GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: May 25, 1978

Project Title: Program for Solar Energy Meteorological Research and Training Site. (Region 3)

Project No: E-16-C01 (Sub-projects are E-15-C01/Williams, E-21-C01/Schlag, B-08-C01/Wood, B-495-001/Sales, B-496-001/Metcalf)

Project Director: Dr. C. G. Justus

Sponsor: Department of Energy

Agreement Period: From 9/30/78 Until 9/29/79 (02 year only)

Type Agreement: Grant No. EG-77-G-05-5604, Modification A001

Amount: $200,000 (E-16-C01 at $118,036; E-15-C01 at $3,468; E-21-C01 at $22,689; B-08-C01 at $3,357; B-495-001 at $41,517; B-496-001 at $10,933)
Cost-sharing of $19 this year in AE; No. E-16-328.

Reports Required: Cont. Mgmt. Summary Rpt., Tech. Status Rpt., Tech. Progress Report (To be submitted by Dr. Justus under E-16-C01)

Sponsor Contact Person (s):

Technical Matters

Michael R. Riches
Department of Energy
Division of Solar Technology
600 E Street, N. W.
Washington, D. C. 20545
(202) 376-4982

Contractual Matters
(thru OCA)

F. O. Christie, Director
Contract Division, ORO
Department of Energy
Oak Ridge Operations
P. O. Box E
(615) 483-8611 Ext. 3-4105
Oak Ridge, TN 37830

Defense Priority Rating: N/A

Assigned to: Aerospace Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- EES Information Office
- EES Reports & Procedures
- Project File (OCA)
- Project Code (GTRI)
- Other__________

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 11/3/80

Project Title: Program for Solar Energy Meteorological Research and Training Site. (Region 3)

Project No: E-16-C01

Project Director: Dr. C. G. Justus

Sponsor: Department of Energy

Effective Termination Date: 9/29/79

Clearance of Accounting Charges: 9/29/79

Grant/Contract Closeout Actions Remaining:
NONE

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ____________

Project continued under E-16-C02

Assigned to: Aerospace Engineering (School/Laboratory)

COPIES TO:

Project Director
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EES Information Office
Project File (OCA)
Project Code (GTRI)
Other C. E. Smith

CA-4 (1/79)

FINANCIAL STATUS REPORT
(Follow instructions on the back)

1. FEDERAL AGENCY AND ORGANIZATIONAL ELEMENT TO WHICH REPORT IS SUBMITTED: Department of Energy

2. FEDERAL GRANT OR OTHER IDENTIFYING NUMBER: EG-77-G-05-5604

OMB Approved No. 80-R0180 | PAGE 1 OF 1 PAGES

3. RECIPIENT ORGANIZATION (Name and complete address, including ZIP code): Georgia Institute of Technology, Atlanta, Georgia 30332

4. EMPLOYER IDENTIFICATION NUMBER: 58-6002023

5. RECIPIENT ACCOUNT NUMBER OR IDENTIFYING NUMBER: B-495-001, B-496-001, E-16-328, E-15-C01/E-16-C01/E-21-C01/G-35-C01/ B-517-001

6. FINAL REPORT: ☐ YES ☒ NO

7. BASIS: ☒ CASH ☐ ACCRUAL

8. PROJECT/GRANT PERIOD (See instructions): FROM (Month, day, year) 9-30-77 TO (Month, day, year) 9-29-82

9. PERIOD COVERED BY THIS REPORT: FROM (Month, day, year) 5-1-78 TO (Month, day, year) 9-29-79

10. STATUS OF FUNDS

PROGRAMS/FUNCTIONS/ACTIVITIES ►	(a) Salaries & Wages	(b) Equipment	(c) Travel	(d) Other Direct	(e) Total Direct	(f) Indirect Costs	TOTAL (g)
a. Net outlays previously reported	$ 93,961.89	$ 59,228.03	$ 2,276.40	$ 25,013.40	$ 180,479.72	$ 65,749.40	$ 246,229.12
b. Total outlays this report period	96,395.91	23,213.64	1,794.00	35,712.77	157,116.32	73,260.89	230,377.21
c. *Less:* Program income credits	-0-	-0-	-0-	-0-	-0-	-0-	-0-
d. Net outlays this report period *(Line b minus line c)*	96,395.91	23,213.64	1,794.00	35,712.77	157,116.32	73,260.89	230,377.21
e. Net outlays to date *(Line a plus line d)*	190,357.80	82,441.67	4,070.40	60,726.17	337,596.04	139,010.29	476,606.33
f. *Less:* Non-Federal share of outlays	33,624.23	-0-	-0-	20,646.98	54,271.21	22,915.04	77,186.25
g. Total Federal share of outlays *(Line e minus line f)*	156,733.57	82,441.67	4,070.40	40,079.19	283,324.83	116,095.25	399,420.08
h. Total unliquidated obligations	-0-	-0-	-0-	-0-	-0-	-0-	-0-
i. *Less:* Non-Federal share of unliquidated obligations shown on line h	-0-	-0-	-0-	-0-	-0-	-0-	-0-
j. Federal share of unliquidated obligations	-0-	-0-	-0-	-0-	-0-	-0-	-0-
k. Total Federal share of outlays and unliquidated obligations	156,733.57	82,441.67	4,070.40	40,079.19	283,324.83	116,095.25	339,420.08
l. Total cumulative amount of Federal funds authorized	157,898.59	82,441.67	4,784.40	39,928.82	285,053.48	114,946.52	400,000.00
m. Unobligated balance of Federal funds	1,165.02	-0-	714.00	(150.37)	1,728.65	(1,148.73)	579.92

11. INDIRECT EXPENSE

a. TYPE OF RATE (Place "X" in appropriate box): ☐ PROVISIONAL ☒ PREDETERMINED ☐ FINAL ☐ FIXED

b. RATE	c. BASE	d. TOTAL AMOUNT	e. FEDERAL SHARE
76%	96,395.91	73,260.89	73,252.53

12. REMARKS: *Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

13. CERTIFICATION

I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL

DATE REPORT SUBMITTED: August 28, 1980

TYPED OR PRINTED NAME AND TITLE: For David V. Welch, Manager, Grants & Contracts Accounting

TELEPHONE (Area code, number and extension): 404/894-4624

G. Justus, Professor

RECEIVED

269-102

STANDARD FORM 269 (7-76)
Prescribed by Office of Management and Budget Cir. No. A-110

E-16-C01

ORO/5604-79/1

PROGRAM FOR SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE (REGION 3)

Quarterly Technical Status and
Contract Management Report

C. G. Justus, Principal Investigator

Georgia Institute of Technology
Atlanta, GA 30332

January, 1979

Report Period October 1, 1978 - December 31, 1978

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DIVISION OF DISTRIBUTED SOLAR TECHNOLOGY

UNDER GRANT EG-77-G-05-5604

Georgia Tech Project E-16-C01

1. PROJECT OBJECTIVES

This broad program of solar energy and meteorological monitoring, training, and research has the following main objectives for the proposed 5 years duration:

(1) to provide for the Southeast Region (Region 3) a set of continuously monitored and quality controlled data on solar radiation and atmospheric phenomena related to solar energy collection, conversion, and storage, and to relate these to the extensive ongoing solar energy research and engineering projects carried out by Georgia Tech and in the Southeast Region.

(2) by analysis of monitoring results at two sites (on campus, adjacent to the Georgia Tech thermal Test facility and off-campus adjacent to the Shenandoah Solar Total Energy Site), determine: a) optimum siting of solar radiation and meteorological monitoring instruments relative to solar energy systems to provide the most representative site data with the least influence from the solar collector systems, b) adequacy and representativeness for the Southeast Region of various methodologies for relating easily measured phenomena (minutes of sunshine, cloud cover, etc.) to engineering quality solar radiation data (direct, diffuse, and global insolation, etc.).

(3) to establish and maintain a training program which will allow: a) undergraduate and graduate engineering students, through elective or minor courses, to become informed in the areas of meteorology and atmospheric science as they relate to solar and wind energy, b) graduate students in the atmospheric sciences to become informed of the specific requirements of monitoring, analysis, interpretation and presentation of meteorological information related to engineering aspects of solar and wind

energy, c) professionals in various fields, through short courses and seminars, to become familiar with the new and rapidly developing aspects of solar energy engineering and technology, especially the radiation monitoring and meteorological aspects of this field.

(4) through cooperation in the 3/2 dual degree program, the National Consortium for Graduate Degrees for Minorities in Engineering and other academic programs, enhance the opportunities for minorities (especially Black American and Puerto Ricans) and women in the solar energy engineering and technology field.

(5) instrumentation and monitoring techniques research and development to enhance the engineering applicability of the solar radiation and meteorological monitoring and to provide better instructional tools through low cost instrument systems for educational purposes.

(6) to investigate, with the fixed site instruments and the portable monitoring units (PMU's), the influence of urban haze and aerosols as well as the high levels of natural turbidity which occur in parts of the Southeast region, and with the PMU's to sample the effects on solar radiation of a wide variety of geography (which spans coastal, piedmont plains, and mountainous within the Southeast region).

2. PROJECT PLAN

A. Research Approach and Definition of Tasks

The proposed project plan is divided into three major tasks, each with several subtasks, as follows:

Task 1: Solar Radiation and Meteorological Monitoring Program

This task includes acquisition, initial calibration, and installation of the solar radiation and meteorological instrumentation at the on-campus (Solar Thermal Test Facility/Wind Turbine Test Facility) site and the off-campus (Shenandoah Georgia Solar Total Energy Project) site. Existing and new instrumentation at these sites will be combined and interfaced through data loggers and magnetic tape recording into a form which can be processed, summarized, and formatted by the main campus computer (CYBER 70/74 system). Annual calibration of the instrumentation, against national standards where appropriate, will be carried out, as well as more frequent field calibration of the radiation monitoring instruments. A carefully monitored program of daily instrument inspection and routine maintenance will also be carried out. The detailed outline of the various subtasks under Task 1 is as follows:

a. Based on the proposed variables to be monitored, the Instrumentation Network Design will be laid out using equipment assigned by Georgia Tech for use on this program and additional units to be purchased with the sponsor's approval.

b. Using the preliminary network design, the Selection, Order, and Delivery will be based on recommendations made at the preliminary review meeting of all of the principal investigators.

c. Before an instrument or support unit is put into service, each piece of equipment will be examined and subjected to an Instrument Check and Certification for conformation to Georgia Tech and vendor specifications.

Instruments which fail to pass inspection will be returned to the vendor for replacement.

d. The design, fabrication, and installation of the Auxiliary Hardware which will house and/or support the instrumentation will be according to recommendations in the above articles, of the respective vendors, and to experience gained through use of similar apparatus.

e. Campus Site Modification and Preparation will be done as necessary to accomodate the new monitoring site and instrumentation.

f. The Relocation of Existing Instruments will be performed expeditiously to prevent a loss of data in the present continuous monitoring system. Exposure and operation of the solar radiation and meteorological monitoring instruments will be in accordance with criteria and guidelines published by the WMO(1971) and the IGY (1958).

g. The Instrumentation will be installed and calibrated after it is received and certified.

h. Campus Site Monitoring for the total system is scheduled to begin during the last month of Year 1, but a continuous monitoring system will have been in use for the entire period.

i. The Shenandoah Monitoring System will be used for the entire period after the "Sandia Solar Monitor System" is installed. This basic instrument package will be augmented by additional equipment. Data from the Shenandoah System will be logged on cassette tape. It will then be reformatted and merged with the campus site monitoring data on the CYBER system and put on magnetic tape.

j. Analytical Software will be developed in a standard format which will be used for all research sites. This format was selected at the project directors meeting in Washington, D. C. Data will be taken for analysis

to the CYBER 70/74 computer for transfer to the standard format and storage in this format on magnetic tape, and for transmittal of the raw and summarized data to the National Climatic Center in Asheville.

k. An Instrumentation Calibration by use of a set of special instruments or by techniques specified by the instrument vendor will be performed quarterly to verify instrument accuracy and to establish a permanent record of possible instrument degradation which would affect the acquired data.

l. At the end of each phase of the program, the set of standards would be taken to the Solar Radiation Calibration Facility in Denver, Colorado for Certification of Standard Instruments.

m. The Data Transfer to the National Climatic Center is scheduled to begin on a monthly basis at the end of Year 1 and would continue for the next 48 months. The data will also be stored at Georgia Tech.

Task 2: Solar Energy/Meteorology Training Program

This task involves development and implementation of on-campus, immediate area, and regional training. Existing graduate courses in general meteorology and boundary layer meteorology will be expanded by a new graduate course (open to seniors) in the area of meteorology for solar and wind energy. This course will include training in instrumentation, data acquisition, reduction and analysis. With the formation of an Atmospheric Sciences academic program anticipated to begin in September 1978, this academic curriculum will offer engineers and engineering technologists the opportunity to learn, as a minor or elective course basis, fundamentals of meteorology as it applies to solar energy engineering and technology. It will also allow meteorologists and atmospheric science students in the new program to interact with and learn about the engi-

neering problems and needs related to solar energy technology. This academic program and related short courses for professionals will be made available as appropriate through a unique instructional TV system to become operational at Georgia Tech in September 1978. A "traveling course" to be put on as a short course or a one quarter course at regional colleges will also be implemented. Initially this will be conducted by Georgia Tech personnel. Later, as arrangements are worked out and the local college has personnel trained to proctor or tutor the course, this will be carried via the TV system, either on a video cassette delivery basis, or if the system is developed, via a satellite TV link.

Task 3: Instrumentation and Monitoring Techniques Research

Various research and development aspects related both to the monitoring and the training program, will be carried out under this task. The location of the two monitoring sites - one on-campus within about two miles from the heart of downtown Atlanta, one at the new town Shenandoah site, about 45 miles from Atlanta - will allow evaluation of urban/rural differences, especially related to urban haze and aerosols. The exposure of the instruments adjacent to the Solar Thermal Test Facility and Wind Turbine Test Facility at Georgia Tech will allow evaluation of potential effects on temperature, moisture, and air flow near such facilities. Hence optimum locations will be evaluated for instruments near solar energy facilities, to provide maximum degree of representativeness and minimum influence from the solar energy system on the meteorological measurements. Many models have been proposed in which various meteorological and simply measured radiation parameters (sunshine hours, temperature, cloud cover, solar declination, etc.) can be used to estimate engineering quality insolation (global and direct insolation, global on inclined surfaces, etc.). Some of these methods are those of Fritz (1957), Angstrom (1956), Black et al (1954), Glover and McCulloch (1958), Sabbagh et al (1977), Liu and Jordan (1960),

Whillier (1956) Bennett (1965), Swartman and Ogunladeo (1967), Reddy (1971a, 1971b), Norris (1966), Masson (1966), Atwater (1974), Lumb (1964), L'Vova (1972), Machta (1974), Paltridge (1974), Lin (1973), and Randall et al (1977). Through NOAA (Machta, private communication) a set of linear regression coefficients is being developed for the 26 rehabilitated solar radiation data stations. Using this model, the National Climatic Center will prepare, by November 1977, solar radiation estimates for 200 stations in the U.S. These data will be put on magnetic tape in SOLMET format. The data from the on-campus and off-campus monitoring sites as well as from the 5 Southeastern sites in the new 35 site NOAA network (Riches, 1975) will be used to study regional relationships between simply monitored parameters and solar radiation data for engineering purposes. Results of the contract study resulting from the recent RFP to Perform a Solar Radiation Data Forecast and Interpolation Analysis will also be applied in this study. Emphasis will be on study of the influence of turbidity (high in parts of the Southeast region), and regional geography (which spans coastal, piedmont plains, and mountain areas). During the second and subsequent years up to three low cost portable monitoring units will be designed and built. These units will be used in the training program as instructional systems for the traveling course to regional colleges. Data from these units will also be used in the analysis of methods to relate simple measured parameters to engineering quality insolation data for the region. Other instrument and monitoring techniques for which research and development projects are envisioned will include:

a. an automatic filter changing wheel for the normal incidence pyrheliometer (to automatically switch on a 1/minute or less basis between clear, OG1, RG2, and RG8 filters),
b. circumsolar radiation with the Lawrence Berkley Labs circumsolar telescope, currently on campus and projected to remain here throughout at least a portion of this project, and

c. an automatic wide field of view camera system to provide a film record of cloud cover conditions.

3. ADMINISTRATIVE STATUS

No changes. Project team and organization is as shown in Figure 3.1.

4. PROGRESS TO DATE

Task 1: Solar Radiation and Meteorological Monitoring Program

a. Instrumentation for the parameters to be monitored is outlined in Table 4.1. The instrumentation network design was completed during the first grant year. No modifications have been required as yet.

b. Additional items delivered during the period are the CSIRO pyrradiometer, temperature, humidity and pressure transducers, and rain gage. All items for the on-campus site have now been delivered.

c. Calibrations have been done on the NIP's using the Active Cavity Radiometer as reference. Sun/shade tests and calibration transfer from the secondary standard PSP calibrated at NOAA Boulder have been completed. The active cavity radiometer was used in the National Intercomparison study at DSET Labs in Phoenix. Results of these calibrations were discussed in the annual report (ORO 15604-78/4).

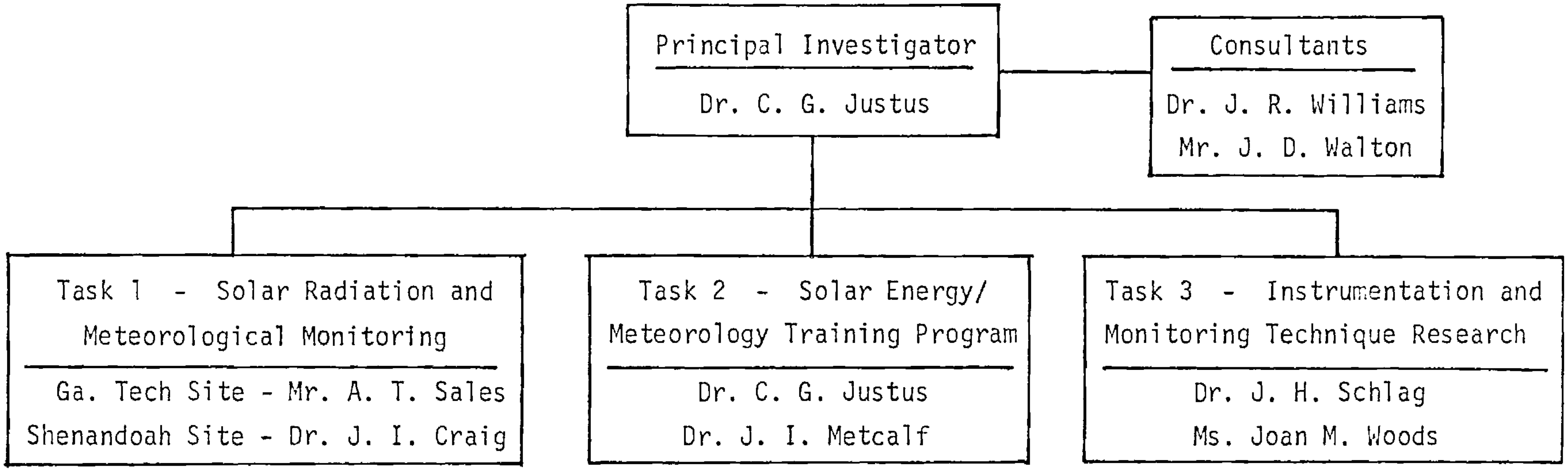

Figure 3.1 - Project Organization Chart

Solar Energy Meteorology
Research and Training Site
Georgia Tech
Atlanta, GA 30332

A. Basic measurements at fixed site on Georgia Tech Campus

Instrument	Signal Type and Level	No. of Signals	Sample Rate	Remarks
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.*	Unshaded; WG 295 dome Global
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Unshaded; RG 630 dome Global spectral
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Shaded; WG 295 dome Diffuse
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Shaded; RG 630 dome Diffuse spectral
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Tilted 34°; WG 295 dome Global tilted
Pyrheliometer (Eppley NIP)	0 to 15 mv DC	1	1 per min.	Direct
Pyrheliometer (Eppley NIP)	0 to 15 mv DC	1	1 per min.	OG 530, RG 630, RG 695 filters Direct spectral
Pyrradiometer (CSIRO)	0 to 50 mv DC	1	1 per min.	Thermopile output Total
UV Pyranometer (Eppley)	0 to 15 mv DC	1	1 per min	UV
Thermometer (Rosemount)	0 to 100 mv DC	2	1 per min. each	Tower mounted, temperature and ΔT
Dew Point Sensor (YSI)	0 to 1 V DC	2	1 per min. each	Tower mounted, 2 levels
Pressure Transducer (SA 363)	0 to 5 V DC	1	1 per min.	
Anemometer (Gill; Young)	0 to 5 V DC	2	1 per min. each	Tower mounted, propeller vane
Wind Vane (Gill; Young)	0 to 5 V DC	2	1 per min. each	Tower mounted, propeller vane
Rain Gauge (SA 552)	0 to 5 V DC	1	1 per min.	

* Sample rates are higher but integrated over 1 minute and recorded as 1 minute averages every minute.

Instrument	Signal Type and Level	No. of Signals	Sample Rate	Remarks
Percent Sunshine (Campbell-Stokes)	NA	NA	1 per hr.	Data reduced manually
Cloud Cover and Current Weather	NA	NA	1 per hr.	Atlanta Airport NWS data

B. Research measurements at fixed site on Georgia Tech Campus

Pyranometer (Spectrolab)	0 to 15 mv DC	1	1 per min.	For comparison with Eppley
Integrating Nephelometer (MRI)	0 - 5 V	1	1 per min.	
Active Cavity Radiometer (TMI)	0 - 5 V	1	special studies	Manual operation as calibration aid
Turbidity (Volz)	NA	NA	Special Studies	Manual operation
Circumsolar Telescope (LBL)	NA	NA	1 scan per 10 min.	Separate recording, automatic operation. Continued operation on campus depends on DOE decisions regarding LBL circumsolar program. Filter wheel radiometer instrument on circumsolar telescope can also be used for aerosol loading and ozone total optical depth determinations.
	(each scan includes a number of radiation and meteorological parameters)			
Spectrometer (Optronics 740 A)	BCD	1	10 per min.	300 to 1070 nm; selectable ste size; at 20 nm steps can get spectrum every 4 min. (If budget permits)
Ozone meter (Dasibi)	0 to 1 V DC	1	1 per min.	Operated on campus when not i field for other project
Anemometer (MRI 1074)	0 to 5 V	2	1 per min. each	tower mounted, wind turbine si
Temperature (thermistor)	0 to 5 V	2	1 per min. each	tower mounted, wind turbine si
Humidity (WM-MH111)	0 to 10 V	2	1 per min. each	tower mounted, wind turbine si

Instrument	Signal Type and Level	No. of Signals	Sample Rate	Remarks
Directional Dustfall (WM-APW 1)	NA	NA	Special studies	Gross Particulate measurements
Lidar	NA	NA	1 per min. (Special studies)	Vertical aerosol profiling. Installation and operation by Dr. G. W. Grams depends on separate agency funding of his program. Also gives times of occurrence of thin cirrus for interpretation of circum-solar data.
Polar Nephelometer	NA	NA	1 per 10 min. (special studies)	Dr. G. W. Grams design. Surface or aircraft (Georgia Tech Convair 240) in situ measurements of angular distribution of light scattering from aerosols. Available when not in use on another project.
aerosol size spectrometer, millipore filters, nuclepore filters	NA	NA	1 per min. (spectrometer) 1 per 10 min. (filters) (special studies)	Refractive index versus wave length for aerosols. Size distributions and shapes of aerosols out to very small size range. Available when not in use on another project (Dr. G. W. Grams equipment).

C. Research measurements at fixed site at Shenandoah (near Newnan, Georgia)

Instrument	Signal Type and Level	No. of Signals	Sample Rate	Remarks
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Unshaded; WG 295 dome
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Unshaded; RG 630 dome
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Shaded; WG 295 dome
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Tilted 34°; WG 295 dome
Pyrheliometer (Eppley NIP)	0 to 15 mv DC	2	1 per min.	Duplicate for redundancy
Pyrheliometer (Eppley NIP)	0 to 15 mv DC	1	1 per min.	WG 295, OG 530, RG 630, RG 69. filters
Pyrradiometer (CSIRO)	0 to 50 mv DC	1	1 per min.	Thermopile output
Thermometer		1	1 per min.	New EG & G portable system
Humidity		1	1 per min.	New EG & G portable system
Pressure Transducer		1	1 per min.	New EG & G portable system
Anemometer		1	1 per min.	New EG & G portable system
Wind Vane		1	1 per min.	New EG & G portable system
Rain Gauge (SA 552)	0 to 5 V DC	1	1 per min.	
UV Pyranometer (Eppley)	0 to 15 mv DC	1	1 per min.	If budget permits
Nephelometer (MRI)	0 to 5 V	1	1 per min.	If budget permits

Table 4.1 cont'd.

D. Measurements with Portable Monitoring Unit

Instrument	Signal Type and Level	No. of Signals	Sample Rate	Remarks
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Unshaded; WG 295 dome
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Shaded (Shade Ring); WG 295 dome
Pyranometer (Eppley PSP)	0 to 15 mv DC	1	1 per min.	Tilted (latitude); WG 295 dome
Pyrheliometer (Eppley NIP)	0 to 15 mv DC	1	1 per min.	WG 295, OG 530, RG 630, RG 695 filters
Thermometer	0 to 100 mv	1	1 per min.	
Dew Point	0 to 1 V	1	1 per min.	
Anemometer	0 to 5 V	1	1 per min.	
Wind Vane	0 to 5 V	1	1 per min.	

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Table 4.2

NIP Calibration Results

Wire Code	Instr. Type	Serial No.	Factory Cal $\mu V/Wm^{-2}$	ACR Calibration avg.	ACR Calibration σ	ACR Calibration σ%	Deviation from Factory Cal %
33	NIP	17008E6	6.64	6.84	0.03	0.5	3.0
34	NIP	17004E6	8.52	8.59	0.02	0.2	0.8
35	NIP	16995E6	7.65	7.75	0.03	0.4	1.3
36	NIP	17003E6	6.76	6.89	0.02	0.2	1.9
32	NIP	13656E6	7.74	7.54	0.03	0.3	-2.6
43	NIP	5266	7.48	7.14	0.01	0.1	-4.6

TABLE 4.3

PSP Calibration Results

Wire Code	Instr. Type	Serial No.	Factory Cal $\mu V/Wm^{-2}$	Sun/Shade Cal $\mu V/Wm^{-2}$			Deviation from Factory Cal, %	Global Ref. to #25 $\mu V/Wm^{-2}$			Deviation from Factory Cal.	Deviation from Sun/Shade
				avg.	σ	σ%		avg.	σ	σ%	%	%
23	PSP	17061F3	9.79	9.67	0.12	1.3	-1.2	9.73	0.01	0.1	-0.6	0.6
24	PSP	17059F3	9.67	9.45	0.05	0.5	-2.3	9.51	0.04	0.4	-1.7	0.6
25	PSP	17063F3	9.82	9.79	0.10	1.0	-0.3	9.80	(assumed value)			
26	PSP	17060F3	9.53	9.34	0.19	2.0	-2.0	9.45	0.01	0.1	-0.8	1.2
27	PSP	17065F3	9.16	9.01	0.11	1.2	-1.6	9.11	0.02	0.2	-0.5	1.1
28	PSP	17064F3	9.57	9.50	0.12	1.3	-0.7	9.57	0.02	0.2	0.0	0.7
29	PSP	17066F3	9.63	9.40	0.02	0.2	-2.4	9.55	0.01	0.1	-0.8	1.6
30	PSP	17062F3	9.73	9.64	0.03	0.3	-0.9	9.75	0.05	0.5	0.2	1.1
31	SR75	77120	10.44	9.91	0.04	0.4	-5.1	9.97	0.01	0.1	-4.5	0.6
37	PSP	15092F3	9.47	9.23	0.05	0.5	-2.5	9.33	0.02	0.2	-1.5	1.1
38	PSP	15224F3	9.50	9.17	0.07	0.8	-3.5	9.28	0.03	0.3	-2.3	1.2
39	PSP	16684F3	9.54	9.39	0.09	1.0	-1.6	9.45	0.04	0.4	-0.9	0.6
42	8-48	15057	11.23	10.85	0.24	2.2	-3.4	11.25	0.13	1.1	0.2	3.7

d. Design, fabrication, and installation of all auxiliary hardware to house and/or support the instrumentation was completed during the period.

e. The contractor for installation of the roof pad, recording shack and meteorological tower on the roof of the Civil Engineering building completed this installation on December 5. Installation of the instrumentation is proceeding and completion for beginning of operations is expected in January.

f. All instruments which were temporarily set up on the roof of the Hinman building, have been transferred to the C. E. roof installation. Relocation of existing instrumentation is now complete.

g. Installation at the permanent site on the Civil Engineering rooftop is essentially complete.

h. Continuous monitoring at the C. E. rooftop installation is scheduled now to begin in January.

i. The 8 channel Shenandoah monitoring system has now been replaced by the 16 channel system recently sent by EG & G. The additional instruments have been added and extended monitoring has begun. The CSIRO pyrradiometer and artificial horizon on the tilted PSP have yet to be installed.

j. A program to calculate direct, diffuse, and global radiation at any time of the day and year has been written. The techniques employed in the program are those documented by Watt Engineering in their recent report (HCP/T2552-01). It is anticipated that this program will be used as an integral part of the quality control analysis of the monitored data. Testing of the program has begun during this reporting period.

k-l. Instrument calibration activities were described above. Secondary standard NIP and PSP units have been received back from Ed Flowers after calibration. The secondary standard NIP was compared against the active cavity radiometer. Calibration of the secondary standard PSP was transferred to the other PSP units via additional simultaneous monitoring.

m. No work was done in this area during this reporting period. Transfer of data to NCC Asheville is expected to begin in February.

Task 2: Solar Energy/Meteorology Training Program

Plans are underway with the Atlanta University Center for the establishment of a dual degree program in the atmospheric sciences area. The Atlanta University Center is a group of traditionally black colleges in the metropolitan Atlanta area. The dual degree program allows students to attend another school, then come to Georgia Tech and receive a degree from both institutes. For example, in the 3/2 dual degree B.S. program a student would attend the other school for 3 years, Georgia Tech for 2, then receive a degree (usually liberal arts oriented) from his original institute and a degree (usually science or engineering) from Georgia Tech. The list of participating colleges with which Georgia Tech is already affiliated in the dual degree program includes 10 traditionally black colleges as well as 20 predominantly women's colleges. Project personnel will also be participating in a short course on solar and wind energy, to be put on by the Atlanta University Center in June, 1979.

A short course on Solar Radiation Measurement and Application will be offered in May, 1979. Description of this course is attached. Discussions have been held with the Center for Media Based Education about the possibilities of TV cassette recording of this short course for offering around the region. The new graduate course Meteorology for Solar and Wind Energy, described in an earlier report, is being offered in the Winter quarter.

A letter has been distributed to other colleges and to businesses within the Southeast Region soliciting ideas for mutual cooperative efforts in the monitoring and training area. A mailing list is being compiled from responses.

Task 3: Instrumentation and Monitoring Techniques Research

Design of the portable monitoring unit was essentially completed. Radiation and meteorological sensors were ordered. A commercial data logger is being considered instead of a "home made" version.

Instead of an automatic filter holder for NIP's, an automatic sun photometer is being designed, with three separate photo cells and three separate fixed filters (500 nm, 880 nm, and 940 nm) to continuously record turbidity and precipitable water data.

An all-sky camera system is being designed as a weather protected, downward-looking, time-lapse camera focused on a reflecting hemisphere, with a digital watch in the field of view for data and time information.

SHORT COURSE DESCRIPTION

SOLAR RADIATION MEASUREMENT & APPLICATIONS

May 21-22, 1979

Georgia Institute of Technology
Continuing Education Courses

FACULTY

Drs. C. G. Justus, J. R. Williams and A. P. Sheppard are the academic administrators for the course. Dr. Justus is a professor in the Atmospheric Sciences Program of the School of Geophysical Sciences. He is the principal investigator of the D.O.E. sponsored Solar Energy Meteorological Research and Training Site program at Georgia Tech. Under this project instrumentation is used to measure a wide variety of solar radiation and related meteorological data. These continuous, well calibrated and quality controlled sets of solar radiation data, to be monitored over an extended period of time, will yield a research-grade solar radiation information data base for solar energy purposes.

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Mr. David L. Christensen, Research Associate, Center for Environmental and Energy Studies, University of Alabama at Huntsville, solar radiation instrumentation and applications.

Dr. G. W. Grams, Professor, School of Geophysical Sciences, Georgia Tech, physical principles of solar radiation and its transport through the atmosphere.

Dr. J. I. Craig, Associate Professor, Aerospace Engineering, Georgia Tech, solar instrumentation and environmental evaluation and design applications.

Dr. J. H. Schlag, Associate Professor, Electrical Engineering, Georgia Tech, solar tracking, recording and processing instrumentation.

Dr. J. I. Metcalf, Senior Research Scientist, Engineering Experiment Station, Georgia Tech, solar radiation transport, atmospheric effects.

COURSE TOPICS

Solar Radiation Characteristics. Descriptive aspects. The solar constant. Solar radiation at the earth's surface.

The Terrestrial Atmosphere. Effects on intensity and directional characteristics of radiation. Molecular and aerosol absorption and scattering. Effects of clouds.

Measurements of Solar Radiation Parameters. Average values and fluctuations. Geographical and seasonal effects.

Instrumentation. Types of instruments. Installation, operation and calibration. Data acquisition and quality control.

Available Solar Radiation Data. Survey of available insolation data, its acquisition and applications.

Applications. Use of solar radiation data in design of energy conversion systems and solar homes and buildings.

SOLAR RADIATION MEASUREMENT AND APPLICATIONS

This course is designed to familiarize the participant with the methods for measuring and utilizing solar radiation information. It will illustrate when and how existing solar radiation data bases may be used in certain engineering applications. For monitoring of solar radiation, the course covers various aspects of monitoring instrumentation, installation, operation, calibration, data acquisition, and processing.

To be offered the week prior to the International Solar Energy Society (ISES) Conference in Atlanta, and immediately before the Solar Heating and Cooling short course at Georgia Tech, this course offers an excellent opportunity to "get up to speed" on solar radiation measurement and applications techniques. It also offers an excellent opportunity to gain first hand knowledge of the numerous solar energy projects on and around the Georgia Tech campus, through tours of facilities during this short course and later in the week, prior to the ISES Conference.

TOUR OF FACILITIES

A tour will be provided of the Solar Energy Meteorological Research and Training Site. This facility includes instrumentation for measurement of global, direct, and diffuse radiation, global on a tilted surface, global and diffuse spectral radiation, UV, IR, atmospheric turbidity, and many associated meteorological parameters.

The Solar Energy Meteorological Research and Training Site program at Georgia Tech is one of eight regional centers around the country, sponsored

by DOE, for purposes of carrying out solar radiation monitoring, research, and training activities. During the tour, participants will get to see the various solar radiation monitoring instrumentation in action, and to use some of them in simple experiments to gain first hand knowledge of their operating characteristics and uses.

FORM ERDA 536
(11/30/76)

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

CONTRACT MANAGEMENT SUMMARY REPORT

1. Contract Identification Program for Solar Energy Meteorological Research and Training Site (Region 3)	2. Reporting Period 10/1/78 through 12/31/78	3. Contract Number EG-77-G-05-5604
4. Contractor (name and address) Georgia Institute of Technology, Atlanta, Georgia 30332		5. Contract Start Date 9/30/77
		6. Contract Completion Date 9/29/79

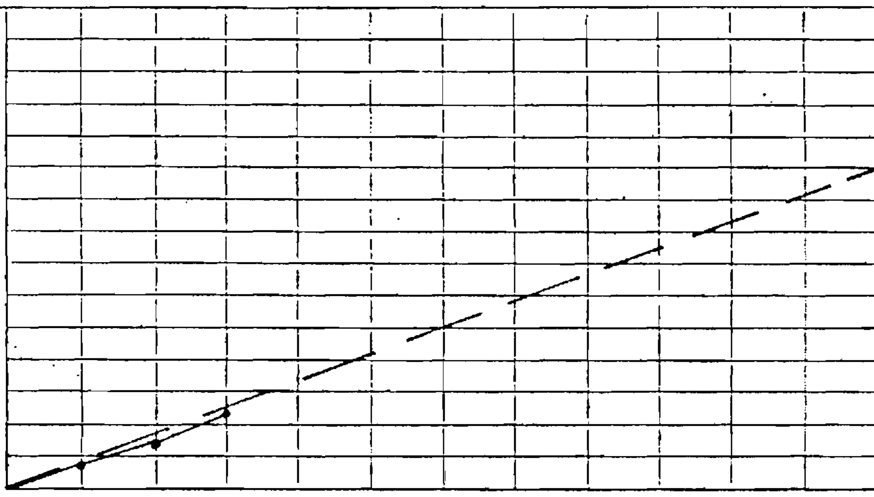
7. Months	O	N	D	J	F	M	A	M	J	J	A	S	8. FY 79

9. Cost Status

a.

Dollars
X
1000

Legend:
------Planned & Approved
______Actual
......Contractors Latest Estimate



e. Actual Costs Prior FYs: $200,000

f. Planned Costs Prior FYs: $200,000

g. Total Projected Accrued Costs for Contract: $400,000

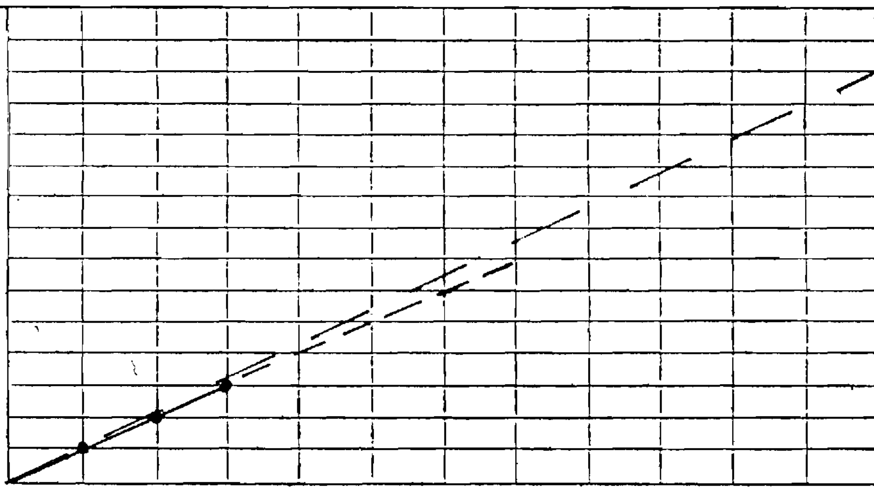
h. Total Contract Value: $400,000

Accrued Costs		O	N	D	J	F	M	A	M	J	J	A	S
	b. Planned	17	33	50									
	c. Actual	15	30	44									
	d. Variance	2	3	6									

10. Manpower Status

a.

Man Months
X
1



e. ~~Actual Manpower Prior FYs~~: 65 man months

f. Planned Manpower Prior FYs: 65 man months

g. Total Projected Manpower for Contract: 59 man months

h. Total Contract Manpower: 59 man months

Manpower		O	N	D	J	F	M	A	M	J	J	A	S
	b. Planned	5	10	15									
	c. Actual	5	10	15									
	d. Variance	0	0	0									

11. Major Milestone Status

a. See attached Detailed Milestone Chart.

b.

c.

d.

e.

f.

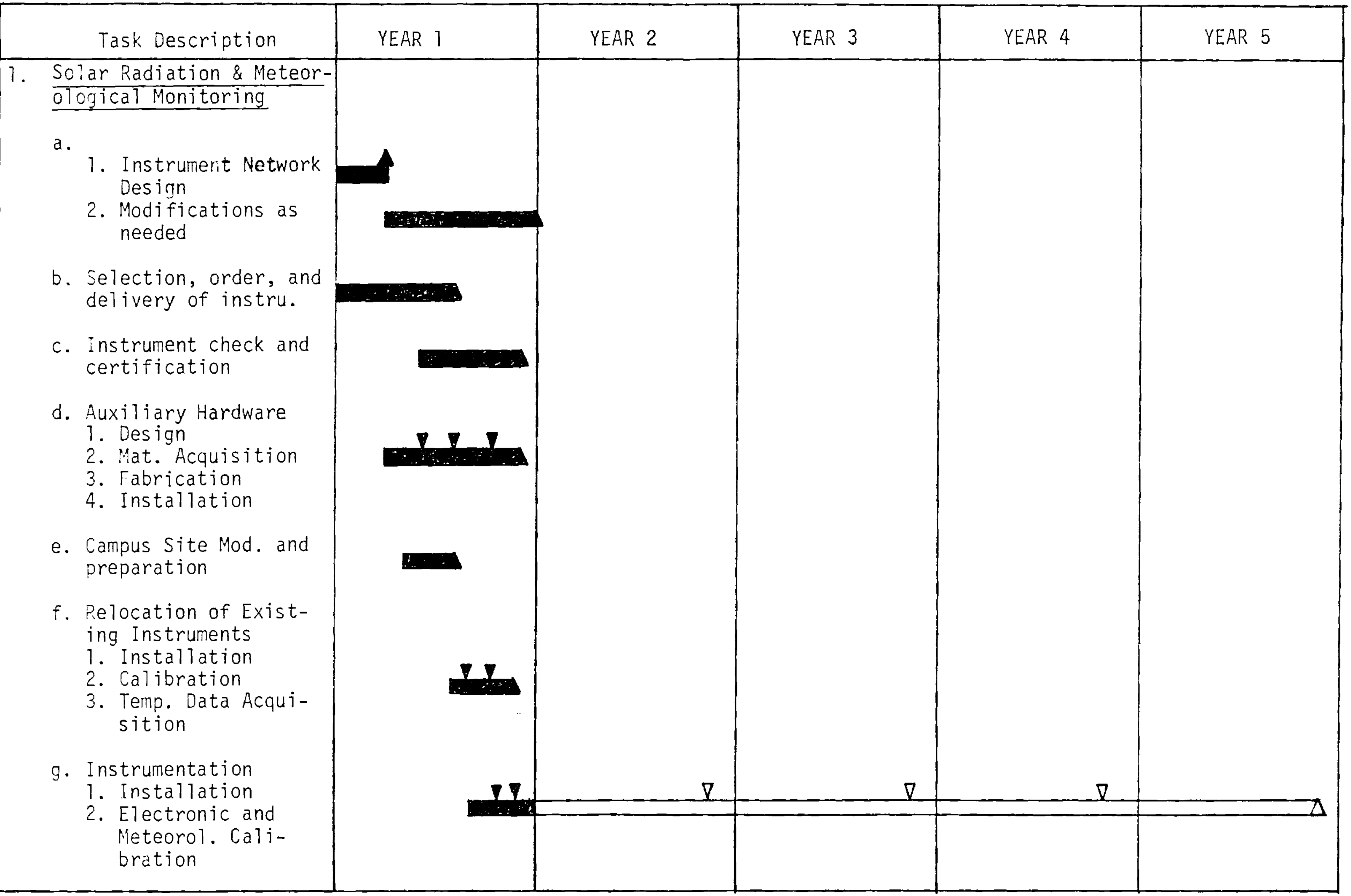
g.

h.

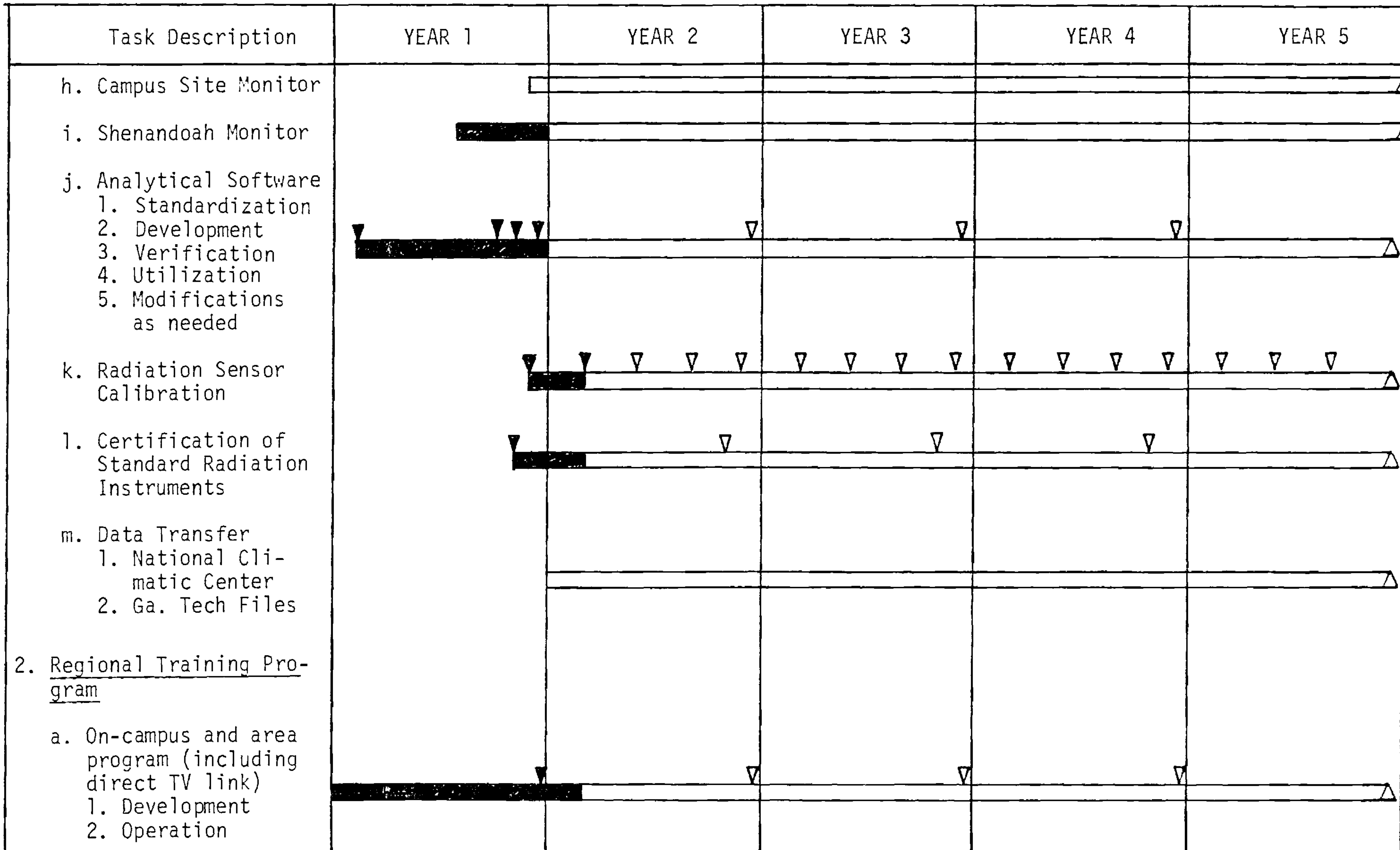
12. Remarks

13. Signature of Contractor's Project Manager and Date	14. Signature of Government Technical Representative and Date

Milestone Chart



Milestone Chart (Cont'd.)



Milestone Chart (Cont'd)

Task Description	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
b. Southeast Region Training Program 1. Develop regional arrangements 2. In-person traveling regional courses 3. Regional TV training courses					
3. <u>Instrument and Monitoring Technical Research</u>					
a. Solar Energy Site Influence					
b. Urban/Rural Comparisons					
c. Analysis of Regional Relations					
d. Portable Monitoring Units (PMU) for Training and Regional Study 1. Design (PMU's) 2. Instrument acquisition 3. Construction and testing 4. Cycle of field operation and training courses		Unit 1	Unit 2	Unit 3	
e. Circumsolar Direct and Total vs. Field of View 1. Research and development 2. Instrument testing and operation					

Milestone Chart (cont'd)

Task Description	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
f. Automatic Filter holder for NIP Spectral Data					
1. Research and development					
2. Testing and operation					
g. Automatic cloud cover camera					
1. Research and development					
2. Testing and operation					
4. <u>Reports and Review Meetings</u>					
Technical Status Reports					
Review Meeting					
Technical Progress Reports					

E-16-C01

ORO/5604-79-2

PROGRAM FOR SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE (REGION 3)

Quarterly Technical Status and Contract Management Report

C. G. Justus, Principal Investigator

Georgia Institute of Technology
Atlanta, GA 30332

April, 1979

Report Period January 1, 1979 - March 31, 1979

PREPARED FOR THE UNITED STATES DEPARTMENT OF ENERGY

DIVISION OF DISTRIBUTED SOLAR TECHNOLOGY

UNDER GRANT EG-77-G-05-5604

Georgia Tech Project E-16-C01

1. PROJECT OBJECTIVES

This broad program of solar energy and meteorological monitoring, training, and research has the following main objectives for the proposed 5 years duration:

(1) to provide for the Southeast Region (Region 3) a set of continuously monitored and quality controlled data on solar radiation and atmospheric phenomena related to solar energy collection, conversion, and storage, and to relate these to the extensive ongoing solar energy research and engineering projects carried out by Georgia Tech and in the Southeast Region.

(2) by analysis of monitoring results at two sites (on campus, adjacent to the Georgia Tech thermal Test facility and off-campus adjacent to the Shenandoah Solar Total Energy Site), determine: a) optimum siting of solar radiation and meteorological monitoring instruments relative to solar energy systems to provide the most representative site data with the least influence from the solar collector systems, b) adequacy and representativeness for the Southeast Region of various methodologies for relating easily measured phenomena (minutes of sunshine, cloud cover, etc.) to engineering quality solar radiation data (direct, diffuse, and global insolation, etc.).

(3) to establish and maintain a training program which will allow: a) undergraduate and graduate engineering students, through elective or minor courses, to become informed in the areas of meteorology and atmospheric science as they relate to solar and wind energy, b) graduate students in the atmospheric sciences to become informed of the specific requirements of monitoring, analysis, interpretation and presentation of meteorological information related to engineering aspects of solar and wind

energy, c) professionals in various fields, through short courses and seminars, to become familiar with the new and rapidly developing aspects of solar energy engineering and technology, especially the radiation monitoring and meteorological aspects of this field.

(4) through cooperation in the 3/2 dual degree program, the National Consortium for Graduate Degrees for Minorities in Engineering and other academic programs, enhance the opportunities for minorities (especially Black American and Puerto Ricans) and women in the solar energy engineering and technology field.

(5) instrumentation and monitoring techniques research and development to enhance the engineering applicability of the solar radiation and meteorological monitoring and to provide better instructional tools through low cost instrument systems for educational purposes.

(6) to investigate, with the fixed site instruments and the portable monitoring units (PMU's), the influence of urban haze and aerosols as well as the high levels of natural turbidity which occur in parts of the Southeast region, and with the PMU's to sample the effects on solar radiation of a wide variety of geography (which spans coastal, piedmont plains, and mountainous within the Southeast region).

2. PROJECT PLAN

A. Research Approach and Definition of Tasks

The proposed project plan is divided into three major tasks, each with several subtasks, as follows:

Task 1: Solar Radiation and Meteorological Monitoring Program

This task includes acquisition, initial calibration, and installation of the solar radiation and meteorological instrumentation at the on-campus (Solar Thermal Test Facility/Wind Turbine Test Facility) site and the off-campus (Shenandoah Georgia Solar Total Energy Project) site. Existing and new instrumentation at these sites will be combined and interfaced through data loggers and magnetic tape recording into a form which can be processed, summarized, and formatted by the main campus computer (CYBER 70/74 system). Annual calibration of the instrumentation, against national standards where appropriate, will be carried out, as well as more frequent field calibration of the radiation monitoring instruments. A carefully monitored program of daily instrument inspection and routine maintenance will also be carried out. The detailed outline of the various subtasks under Task 1 is as follows:

a. Based on the proposed variables to be monitored, the Instrumentation Network Design will be laid out using equipment assigned by Georgia Tech for use on this program and additional units to be purchased with the sponsor's approval.

b. Using the preliminary network design, the Selection, Order, and Delivery will be based on recommendations made at the preliminary review meeting of all of the principal investigators.

c. Before an instrument or support unit is put into service, each piece of equipment will be examined and subjected to an Instrument Check and Certification for conformation to Georgia Tech and vendor specifications.

Instruments which fail to pass inspection will be returned to the vendor for replacement.

d. The design, fabrication, and installation of the Auxiliary Hardware which will house and/or support the instrumentation will be according to recommendations in the above articles, of the respective vendors, and to experience gained through use of similar apparatus.

e. Campus Site Modification and Preparation will be done as necessary to accomodate the new monitoring site and instrumentation.

f. The Relocation of Existing Instruments will be performed expeditiously to prevent a loss of data in the present continuous monitoring system. Exposure and operation of the solar radiation and meteorological monitoring instruments will be in accordance with criteria and guidelines published by the WMO(1971) and the IGY (1958).

g. The Instrumentation will be installed and calibrated after it is received and certified.

h. Campus Site Monitoring for the total system is scheduled to begin during the last month of Year 1, but a continuous monitoring system will have been in use for the entire period.

i. The Shenandoah Monitoring System will be used for the entire period after the "Sandia Solar Monitor System" is installed. This basic instrument package will be augmented by additional equipment. Data from the Shenandoah System will be logged on cassette tape. It will then be reformatted and merged with the campus site monitoring data on the CYBER system and put on magnetic tape.

j. Analytical Software will be developed in a standard format which will be used for all research sites. This format was selected at the project directors meeting in Washington, D. C. Data will be taken for analysis

to the CYBER 70/74 computer for transfer to the standard format and storage in this format on magnetic tape, and for transmittal of the raw and summarized data to the National Climatic Center in Asheville.

k. An Instrumentation Calibration by use of a set of special instruments or by techniques specified by the instrument vendor will be performed quarterly to verify instrument accuracy and to establish a permanent record of possible instrument degradation which would affect the acquired data.

l. At the end of each phase of the program, the set of standards would be taken to the Solar Radiation Calibration Facility in Denver, Colorado for Certification of Standard Instruments.

m. The Data Transfer to the National Climatic Center is scheduled to begin on a monthly basis at the end of Year 1 and would continue for the next 48 months. The data will also be stored at Georgia Tech.

Task 2: Solar Energy/Meteorology Training Program

This task involves development and implementation of on-campus, immediate area, and regional training. Existing graduate courses in general meteorology and boundary layer meteorology will be expanded by a new graduate course (open to seniors) in the area of meteorology for solar and wind energy. This course will include training in instrumentation, data acquisition, reduction and analysis. With the formation of an Atmospheric Sciences academic program anticipated to begin in September 1978, this academic curriculum will offer engineers and engineering technologists the opportunity to learn, as a minor or elective course basis, fundamentals of meteorology as it applies to solar energy engineering and technology. It will also allow meteorologists and atmospheric science students in the new program to interact with and learn about the engi-

neering problems and needs related to solar energy technology. This academic program and related short courses for professionals will be made available as appropriate through a unique instructional TV system to become operational at Georgia Tech in September 1978. A "traveling course" to be put on as a short course or a one quarter course at regional colleges will also be implemented. Initially this will be conducted by Georgia Tech personnel. Later, as arrangements are worked out and the local college has personnel trained to proctor or tutor the course, this will be carried via the TV system, either on a video cassette delivery basis, or if the system is developed, via a satellite TV link.

Task 3: Instrumentation and Monitoring Techniques Research

Various research and development aspects related both to the monitoring and the training program, will be carried out under this task. The location of the two monitoring sites - one on-campus within about two miles from the heart of downtown Atlanta, one at the new town Shenandoah site, about 45 miles from Atlanta - will allow evaluation of urban/rural differences, especially related to urban haze and aerosols. The exposure of the instruments adjacent to the Solar Thermal Test Facility and Wind Turbine Test Facility at Georgia Tech will allow evaluation of potential effects on temperature, moisture, and air flow near such facilities. Hence optimum locations will be evaluated for instruments near solar energy facilities, to provide maximum degree of representativeness and minimum influence from the solar energy system on the meteorological measurements. Many models have been proposed in which various meteorological and simply measured radiation parameters (sunshine hours, temperature, cloud cover, solar declination, etc.) can be used to estimate engineering quality insolation (global and direct insolation, global on inclined surfaces, etc.). Some of these methods are those of Fritz (1957), Angstrom (1956), Black et al (1954), Glover and McCulloch (1958), Sabbagh et al (1977), Liu and Jordan (1960),

Whillier (1956) Bennett (1965), Swartman and Ogunladeo (1967), Reddy (1971a, 1971b), Norris (1966), Masson (1966), Atwater (1974), Lumb (1964), L'Vova (1972), Machta (1974), Paltridge (1974), Lin (1973), and Randall et al (1977). Through NOAA (Machta, private communication) a set of linear regression coefficients is being developed for the 26 rehabilitated solar radiation data stations. Using this model, the National Climatic Center will prepare, by November 1977, solar radiation estimates for 200 stations in the U.S. These data will be put on magnetic tape in SOLMET format. The data from the on-campus and off-campus monitoring sites as well as from the 5 Southeastern sites in the new 35 site NOAA network (Riches, 1975) will be used to study regional relationships between simply monitored parameters and solar radiation data for engineering purposes. Results of the contract study resulting from the recent RFP to Perform a Solar Radiation Data Forecast and Interpolation Analysis will also be applied in this study. Emphasis will be on study of the influence of turbidity (high in parts of the Southeast region), and regional geography (which spans coastal, piedmont plains, and mountain areas). During the second and subsequent years up to three low cost portable monitoring units will be designed and built. These units will be used in the training program as instructional systems for the traveling course to regional colleges. Data from these units will also be used in the analysis of methods to relate simple measured parameters to engineering quality insolation data for the region. Other instrument and monitoring techniques for which research and development projects are envisioned will include:

a. an automatic filter changing wheel for the normal incidence pyrheliometer (to automatically switch on a 1/minute or less basis between clear, OG1, RG2, and RG8 filters),

b. circumsolar radiation with the Lawrence Berkley Labs circumsolar telescope, currently on campus and projected to remain here throughout at least a portion of this project, and

c. an automatic wide field of view camera system to provide a film record of cloud cover conditions.

3. ADMINISTRATIVE STATUS

No changes. Project team and organization is as shown in Figure 3.1.

4. PROGRESS TO DATE

Task 1: Solar Radiation and Meteorological Monitoring Program

a. Completed in prior period. No modifications required.

b. Completed in prior period. No modifications required.

c. Completed in prior period.

d. Completed in prior period.

e. The campus site installation was completed in January. However, RF interference in the instrumentation for an adjacent FM student station antenna precluded accurate data collection. This station had been scheduled for relocation before the end of 1978. However, equipment delivery problems meant that they actually relocated their antenna in late March. Only then could the campus site operation begin recording usable data.

f. Completed in prior period.

g. A re-calibration of all of the instruments has been done at the on-campus site, after the RF interference was removed and the FM radio station moved to its new, distant, location.

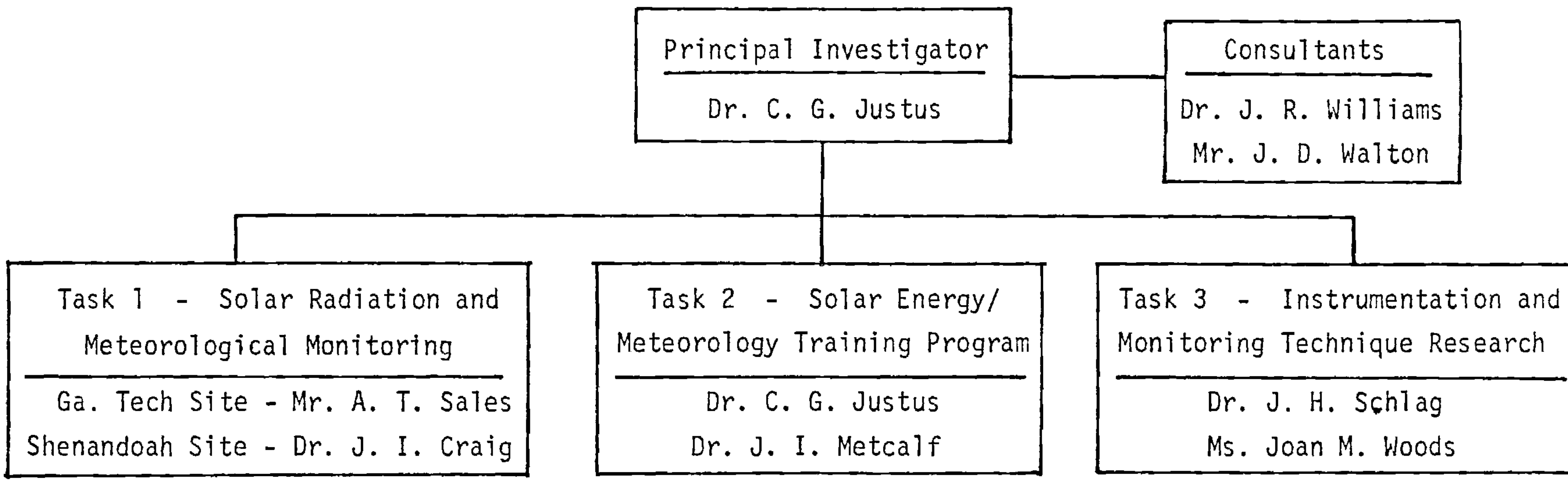


Figure 3.1 - Project Organization Chart

h. Some monitoring problems were noticed when the RF interference source was relocated which could not be detected earlier within the noise levels. Continuous monitoring for archival purposes should now begin about May 1, 1979. Some data, although not continuous, will be available from about March 20 through April 30, 1979.

i. The Shenandoah monitoring has been operational for several months now and these data have been reduced. A re-calibration of these instruments is scheduled for early May.

j. The quality control program is still in final stages of preparation. One problem has been the changes in sorting order and format details which have been distributed by NCC. These changes have caused considerable re-programming to be required.

k. The on-campus site instruments were calibrated against the Kendall active cavity radiometer through direct comparison (NIP's) and sun/shade calibration (PSP's). The PSP's were also compared against the working standard which was calibrated by Ed Flowers. A similar calibration test is planned for the Shenandoah site.

l. A problem has been noted with the working standard NIP. Its calibration sensitivity as determined by active cavity radiometer compared well with the Eppley value and that determined by Ed Flowers. However, the NOAA temperature sensitivity curve showed considerable disagreement with that provided by Eppley. The instrument has been returned to Eppley and is being sent back to NOAA to re-check this discrepancy.

m. Transfer of data from the two sites (campus and Shenandoah) to NCC is expected to begin about July, 1979.

Task 2: Solar Energy Meteorology Training Program

A special University/NOAA workshop was organized at the suggestion of Monte Poindexter. A letter report to him and an attendance list is attached.

A short course on "Solar Radiation Measurement and Applications" is planned for May 21-22, 1979. A course description is attached.

Task 3: Instrumentation and Monitoring Techniques Research

All of the components for the portable monitoring unit have been received. System integration and checkout will begin shortly.

The all-sky camera system design is complete and all components are on-hand. Fabrication of the camera stand is about to begin. Installation is scheduled for some time in late May or early June.

Manual readings with the sunphotometers have begun routinely for analysis of turbidity information. Design work on an automated sunphotometer continues.

A design for an automatic sunshine duration recorder, using the NIP, is being worked on. This will be an amplifier which goes full scale (10 V) if the direct exceeds threshold (adjustable between 70 and 250 W/m^2) and zero output if the direct is below threshold. Averaging the output from this amplifier will provide a direct measurement of sunshine duration.

The integrating nephelometer is in operation and the automatic cycling device for the heater to operate and high humidity is being installed.

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Dr. J. H. Schlag, Associate Professor, Electrical Engineering, Georgia Tech, solar tracking, recording and processing instrumentation.

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GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF GEOPHYSICAL SCIENCES

Atlanta, Georgia 30332
(404) ~~XXXXXXX~~
894-3890

April 10, 1979

Mr. Monte Poindexter
NOAA
8060 13th Street
Silver Spring, MD 20910

Dear Monte:

Enclosed is an attendance list from our NOAA/University Solar Radiation Workshop, 30 March 1979. It was very successful, thanks to your efforts, and reports of it were well received at the review meeting in Denver.

Some of the points which came up at the workshop were:

1) The solar radiation equipment is perhaps the most time consuming measurement device at the NWS offices. Although designed as a "hands-off" system, it does not work this way in practice. One tracker required hourly correction to stay on the sun. One backup printer would not operate properly with the requested "high quality" printer paper but did perform well with "newsprint" grade paper (which then does not store well at CEAS or NCC).

2) More complete documentation for the NWS site technicians is needed for them to insure proper operation and maintenance of calibration of the equipment.

3) Some sites (Blue Hill was mentioned in particular) are "noisier" now than they used to be, in spite of apparent care and quality control by the local observers. Based on some observed RF interference at Georgia Tech (in high field situation, next to FM radio station), it was speculated that RF noise may be of some problem at certain observing sites (especially if radar and aircraft radio transmitters are adjacent to the sensors, cables, or recording equipment).

4) Many of the MIC's had the mistaken impression that there was little interest in these radiation measurements. Our workshop was very valuable in informing them of the interest in the radiation data and its applications to solar energy systems. The opportunity of the CEAS and NCC people to brief the MIC's was especially valuable.

Again, thanks for your efforts in arranging for the official support and travel funding for the NOAA people.

Yours truly,

C. G. Justus

CGJ/sg

NOAA/UNIVERSITY SOLAR
RADIATION WORKSHOP
30 March 1979
Attendance List

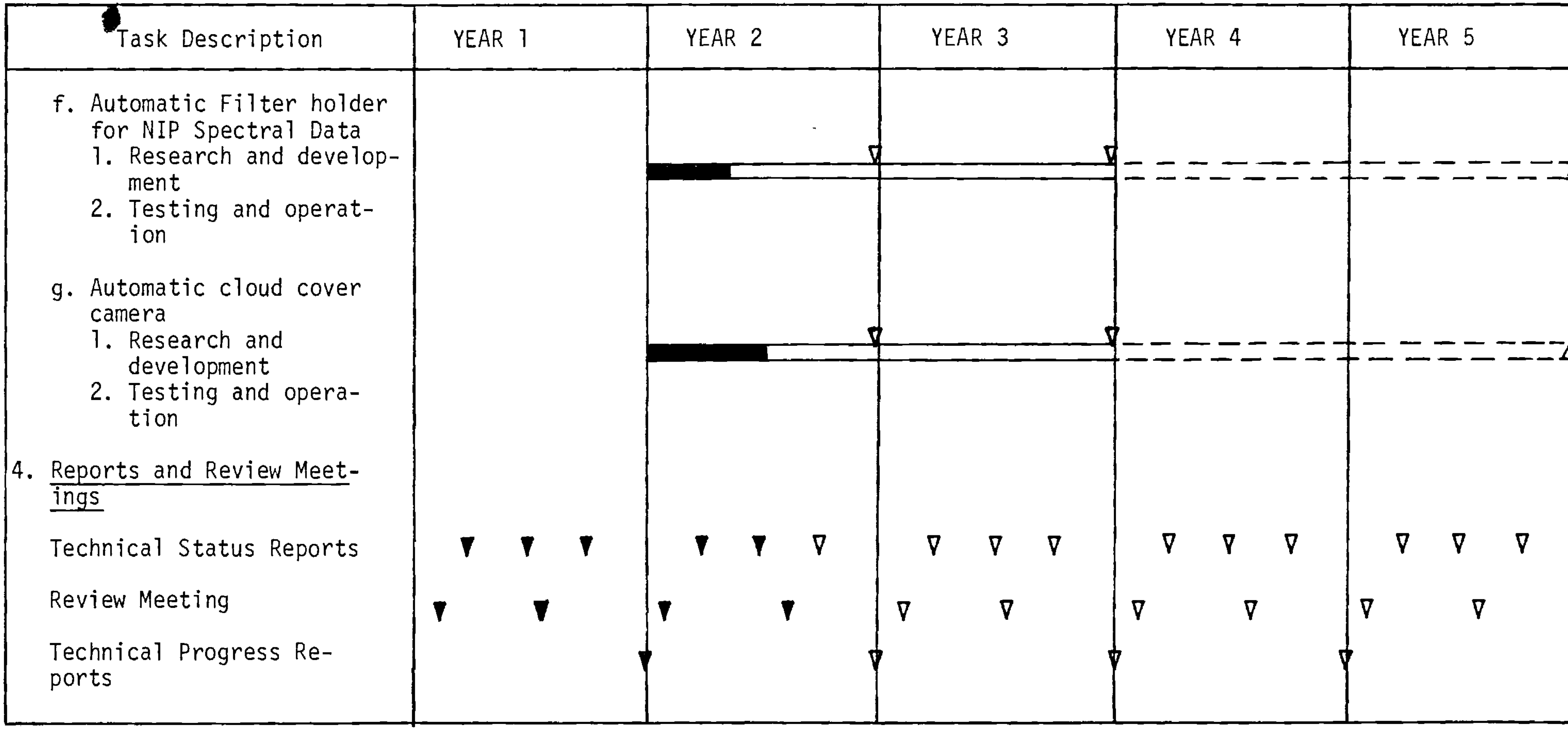
Name	Affiliation and Address	Telephone
Robert O. Cole	NWS/NHC P. O. Box 8286 Coral Gables, FL 33134	305-666-4612
Jose A. Colón	National Weather Service/WSFD Isla Verde International Airport San Juan, Puerto Rico 00913	809-791-0376
J. I. Craig	School of Aerospace Engineering Georgia Institute of Technology Atlanta, GA 30332	404-894-3042
D. R. Davis	National Weather Service 3230 Capital Circle, S.W. Tallahassee, FL 32304	904-576-1811
Eddie Dickens	NOAA-CEAS Page Building #2 3300 Whitehaven Street Washington, D. C. 20007	202-634-7349
Carlos Dunn	NWS Forecast Office 10001 International Boulevard Atlanta, GA 30354	404-762-0636
Jere Gallup	National Weather Service Environmental Studies Service Center Nuclear Science Center Auburn University Auburn, AL 36830	205-826-4514
C. G. Justus	School of Geophysical Sciences Georgia Institute of Technology Atlanta, GA 30332	404-894-3890
Derrel Martin	National Weather Service 322 Knapp Boulevard Nashville, TN 37217	615-361-3062
D. R. Matt	ATDL/NOAA Box E Oak Ridge, TN 37830	FTS-626-1247 615-576-1247

Name	Affiliation and Address	Telephone
John McClain MIC	NOAA - National Weather Service P. O. Box 165 Morrisville, NC 27560	919-781-2
J. I. Metcalf	School of Geophysical Sciences Georgia Institute of Technology Atlanta, GA 30332	404-894-38
Jack Pellett	NOAA/NCC Climatological Analysis Division Federal Building Asheville, NC 28801	704-258-28 ext. 283
Martin Predoehl	NOAA-CEAS Page Building #2 3300 Whitehaven Street Washington, D. C. 20007	202-634-734
C. A. Rigney W521x1	National Weather Service Data Systems Division 8060 13th Street Silver Spring, MD 20910	301-427-779
A. T. Sales	Engineering Experiment Station Georgia Institute of Technology Atlanta, GA 30332	404-894-365
Jay Schlag	School of Electrical Engineering Georgia Institute of Technology Atlanta, GA 30332	404-894-293
Joan M. Wood	Southern Solar Energy Center 2300 Peachford Road Atlanta, GA 30338	404-457-440

Milestone Chart

Task Description	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1. <u>Solar Radiation & Meteorological Monitoring</u>					
a. 1. Instrument Network Design 2. Modifications as needed					
b. Selection, order, and delivery of instru.					
c. Instrument check and certification					
d. Auxiliary Hardware 1. Design 2. Mat. Acquisition 3. Fabrication 4. Installation					
e. Campus Site Mod. and preparation					
f. Relocation of Existing Instruments 1. Installation 2. Calibration 3. Temp. Data Acquisition					
g. Instrumentation 1. Installation 2. Electronic and Meteorol. Calibration					

Milestone Chart (cont'd)



E-16-C01

ORO/5604-79-3

PROGRAM FOR SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE (REGION 3)

Quarterly Technical Status and
Contract Management Report

C. G. Justus, Principal Investigator

Georgia Institute of Technology
Atlanta, GA 30332

July, 1979

Report Period April 1, 1979 - June 30, 1979

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DIVISION OF DISTRIBUTED SOLAR TECHNOLOGY

UNDER GRANT EG-77-G-05-5604

Georgia Tech Project E-16-C01

1. PROJECT OBJECTIVES

This broad program of solar energy and meteorological monitoring, training, and research has the following main objectives for the proposed 5 years duration:

(1) to provide for the Southeast Region (Region 3) a set of continuously monitored and quality controlled data on solar radiation and atmospheric phenomena related to solar energy collection, conversion, and storage, and to relate these to the extensive ongoing solar energy research and engineering projects carried out by Georgia Tech and in the Southeast Region.

(2) by analysis of monitoring results at two sites (on campus, adjacent to the Georgia Tech thermal Test facility and off-campus adjacent to the Shenandoah Solar Total Energy Site), determine: a) optimum siting of solar radiation and meteorological monitoring instruments relative to solar energy systems to provide the most representative site data with the least influence from the solar collector systems, b) adequacy and representativeness for the Southeast Region of various methodologies for relating easily measured phenomena (minutes of sunshine, cloud cover, etc.) to engineering quality solar radiation data (direct, diffuse, and global insolation, etc.).

(3) to establish and maintain a training program which will allow: a) undergraduate and graduate engineering students, through elective or minor courses, to become informed in the areas of meteorology and atmospheric science as they relate to solar and wind energy, b) graduate students in the atmospheric sciences to become informed of the specific requirements of monitoring, analysis, interpretation and presentation of meteorological information related to engineering aspects of solar and wind

energy, c) professionals in various fields, through short courses and seminars, to become familiar with the new and rapidly developing aspects of solar energy engineering and technology, especially the radiation monitoring and meteorological aspects of this field.

(4) through cooperation in the 3/2 dual degree program, the National Consortium for Graduate Degrees for Minorities in Engineering and other academic programs, enhance the opportunities for minorities (especially Black American and Puerto Ricans) and women in the solar energy engineering and technology field.

(5) instrumentation and monitoring techniques research and development to enhance the engineering applicability of the solar radiation and meteorological monitoring and to provide better instructional tools through low cost instrument systems for educational purposes.

(6) to investigate, with the fixed site instruments and the portable monitoring units (PMU's), the influence of urban haze and aerosols as well as the high levels of natural turbidity which occur in parts of the Southeast region, and with the PMU's to sample the effects on solar radiation of a wide variety of geography (which spans coastal, piedmont plains, and mountainous within the Southeast region).

2. PROJECT PLAN

A. Research Approach and Definition of Tasks

The proposed project plan is divided into three major tasks, each with several subtasks, as follows:

Task 1: Solar Radiation and Meteorological Monitoring Program

This task includes acquisition, initial calibration, and installation of the solar radiation and meteorological instrumentation at the on-campus (Solar Thermal Test Facility/Wind Turbine Test Facility) site and the off-campus (Shenandoah Georgia Solar Total Energy Project) site. Existing and new instrumentation at these sites will be combined and interfaced through data loggers and magnetic tape recording into a form which can be processed, summarized, and formatted by the main campus computer (CYBER 70/74 system). Annual calibration of the instrumentation, against national standards where appropriate, will be carried out, as well as more frequent field calibration of the radiation monitoring instruments. A carefully monitored program of daily instrument inspection and routine maintenance will also be carried out. The detailed outline of the various subtasks under Task 1 is as follows:

a. Based on the proposed variables to be monitored, the Instrumentation Network Design will be laid out using equipment assigned by Georgia Tech for use on this program and additional units to be purchased with the sponsor's approval.

b. Using the preliminary network design, the Selection, Order, and Delivery will be based on recommendations made at the preliminary review meeting of all of the principal investigators.

c. Before an instrument or support unit is put into service, each piece of equipment will be examined and subjected to an Instrument Check and Certification for conformation to Georgia Tech and vendor specifications.

Instruments which fail to pass inspection will be returned to the vendor for replacement.

d. The design, fabrication, and installation of the Auxiliary Hardware which will house and/or support the instrumentation will be according to recommendations in the above articles, of the respective vendors, and to experience gained through use of similar apparatus.

e. Campus Site Modification and Preparation will be done as necessary to accomodate the new monitoring site and instrumentation.

f. The Relocation of Existing Instruments will be performed expeditiously to prevent a loss of data in the present continuous monitoring system. Exposure and operation of the solar radiation and meteorological monitoring instruments will be in accordance with criteria and guidelines published by the WMO(1971) and the IGY (1958).

g. The Instrumentation will be installed and calibrated after it is received and certified.

h. Campus Site Monitoring for the total system is scheduled to begin during the last month of Year 1, but a continuous monitoring system will have been in use for the entire period.

i. The Shenandoah Monitoring System will be used for the entire period after the "Sandia Solar Monitor System" is installed. This basic instrument package will be augmented by additional equipment. Data from the Shenandoah System will be logged on cassette tape. It will then be reformatted and merged with the campus site monitoring data on the CYBER system and put on magnetic tape.

j. Analytical Software will be developed in a standard format which will be used for all research sites. This format was selected at the project directors meeting in Washington, D. C. Data will be taken for analysis

to the CYBER 70/74 computer for transfer to the standard format and storage in this format on magnetic tape, and for transmittal of the raw and summarized data to the National Climatic Center in Asheville.

k. An Instrumentation Calibration by use of a set of special instruments or by techniques specified by the instrument vendor will be performed quarterly to verify instrument accuracy and to establish a permanent record of possible instrument degradation which would affect the acquired data.

l. At the end of each phase of the program, the set of standards would be taken to the Solar Radiation Calibration Facility in Denver, Colorado for Certification of Standard Instruments.

m. The Data Transfer to the National Climatic Center is scheduled to begin on a monthly basis at the end of Year 1 and would continue for the next 48 months. The data will also be stored at Georgia Tech.

Task 2: Solar Energy/Meteorology Training Program

This task involves development and implementation of on-campus, immediate area, and regional training. Existing graduate courses in general meteorology and boundary layer meteorology will be expanded by a new graduate course (open to seniors) in the area of meteorology for solar and wind energy. This course will include training in instrumentation, data acquisition, reduction and analysis. With the formation of an Atmospheric Sciences academic program anticipated to begin in September 1978, this academic curriculum will offer engineers and engineering technologists the opportunity to learn, as a minor or elective course basis, fundamentals of meteorology as it applies to solar energy engineering and technology. It will also allow meteorologists and atmospheric science students in the new program to interact with and learn about the engi-

neering problems and needs related to solar energy technology. This academic program and related short courses for professionals will be made available as appropriate through a unique instructional TV system to become operational at Georgia Tech in September 1978. A "traveling course" to be put on as a short course or a one quarter course at regional colleges will also be implemented. Initially this will be conducted by Georgia Tech personnel. Later, as arrangements are worked out and the local college has personnel trained to proctor or tutor the course, this will be carried via the TV system, either on a video cassette delivery basis, or if the system is developed, via a satellite TV link.

Task 3: Instrumentation and Monitoring Techniques Research

Various research and development aspects related both to the monitoring and the training program, will be carried out under this task. The location of the two monitoring sites - one on-campus within about two miles from the heart of downtown Atlanta, one at the new town Shenandoah site, about 45 miles from Atlanta - will allow evaluation of urban/rural differences, especially related to urban haze and aerosols. The exposure of the instruments adjacent to the Solar Thermal Test Facility and Wind Turbine Test Facility at Georgia Tech will allow evaluation of potential effects on temperature, moisture, and air flow near such facilities. Hence optimum locations will be evaluated for instruments near solar energy facilities, to provide maximum degree of representativeness and minimum influence from the solar energy system on the meteorological measurements. Many models have been proposed in which various meteorological and simply measured radiation parameters (sunshine hours, temperature, cloud cover, solar declination, etc.) can be used to estimate engineering quality insolation (global and direct insolation, global on inclined surfaces, etc.). Some of these methods are those of Fritz (1957), Angstrom (1956), Black et al (1954), Glover and McCulloch (1958), Sabbagh et al (1977), Liu and Jordan (1960),

Whillier (1956) Bennett (1965), Swartman and Ogunladeo (1967), Reddy (1971a, 1971b), Norris (1966), Masson (1966), Atwater (1974), Lumb (1964), L'Vova (1972), Machta (1974), Paltridge (1974), Lin (1973), and Randall et al (1977). Through NOAA (Machta, private communication) a set of linear regression coefficients is being developed for the 26 rehabilitated solar radiation data stations. Using this model, the National Climatic Center will prepare, by November 1977, solar radiation estimates for 200 stations in the U.S. These data will be put on magnetic tape in SOLMET format. The data from the on-campus and off-campus monitoring sites as well as from the 5 Southeastern sites in the new 35 site NOAA network (Riches, 1975) will be used to study regional relationships between simply monitored parameters and solar radiation data for engineering purposes. Results of the contract study resulting from the recent RFP to Perform a Solar Radiation Data Forecast and Interpolation Analysis will also be applied in this study. Emphasis will be on study of the influence of turbidity (high in parts of the Southeast region), and regional geography (which spans coastal, piedmont plains, and mountain areas). During the second and subsequent years up to three low cost portable monitoring units will be designed and built. These units will be used in the training program as instructional systems for the traveling course to regional colleges. Data from these units will also be used in the analysis of methods to relate simple measured parameters to engineering quality insolation data for the region. Other instrument and monitoring techniques for which research and development projects are envisioned will include:

a. an automatic filter changing wheel for the normal incidence pyrheliometer (to automatically switch on a 1/minute or less basis between clear, OG1, RG2, and RG8 filters),

b. circumsolar radiation with the Lawrence Berkley Labs circumsolar telescope, currently on campus and projected to remain here throughout at least a portion of this project, and

c. an automatic wide field of view camera system to provide a film record of cloud cover conditions.

3. ADMINISTRATIVE STATUS

Joan Wood has now left Georgia Tech to work with the Southern Solar Energy Center. The project team and organization is now as shown in Figure 3.1.

4. PROGRESS TO DATE

Task 1: Solar Radiation and Meteorological Monitoring Program

a. Completed in prior period. No modifications required.

b. Completed in prior period. No modifications required.

c. Completed in prior period.

d. Completed in prior period.

e. Completed in prior period. Campus site now in full operation.

f. Completed in prior period.

g. A re-calibration of all of the instruments was done before campus site archive data collection was begun. Another re-calibration test is scheduled for next quarter.

h. Campus-site monitoring is now being done. Except for the usual maintenance, all instrumentation is functioning properly.

i. The Shenandoah monitoring system is now in operation. A monthly report for the month of July is attached.

j. The quality control program has been implemented in the real-time serial output, used to spot check the output from the on-campus

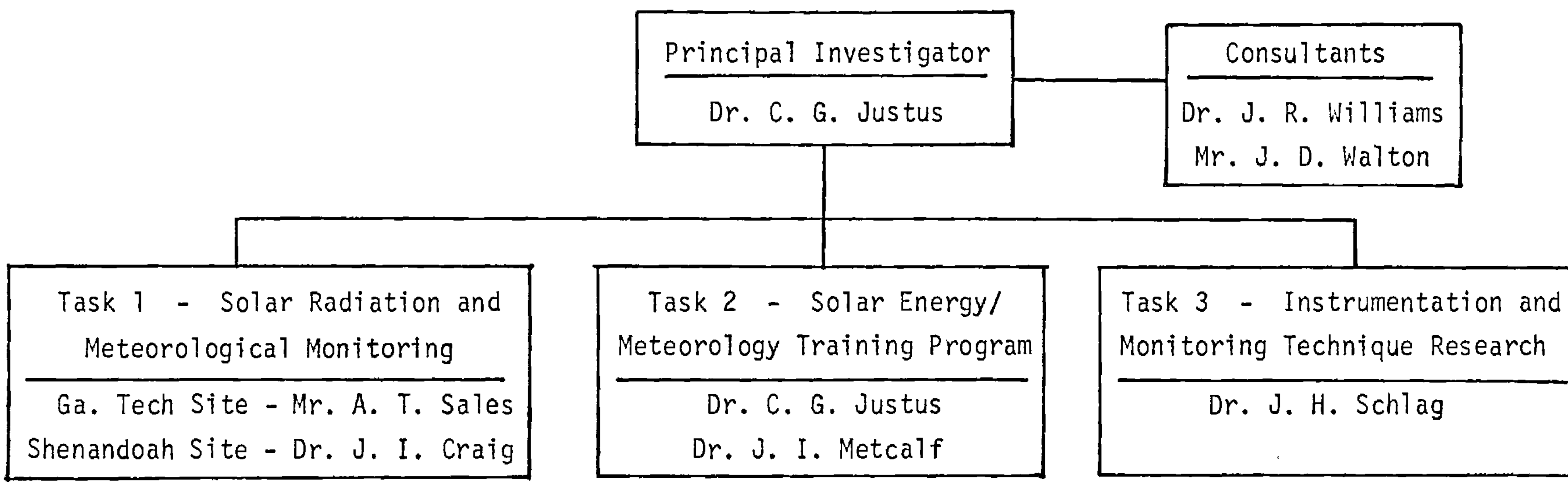


Figure 3.1 - Project Organization Chart

site. Final programming of the complete quality control process for the tape data will require about three more weeks.

k. See item g, above.

l. The working standard NIP has been received from Ed Flowers. Discrepancies still exist between the temperature sensitivity observed by NOAA and by Eppley Labs. Further comparisons and checks against the Kendall active cavity radiometer will be done.

m. Transfer of data from the on-campus and Shenandoah sites will begin in a few more weeks, as soon as the backlog of tape data is processed in the quality control program.

Task 2: Solar Energy/Meteorology Training Program

The short course "Solar Radiation Measurement and Applications" was successfully conducted on May 21-22, 1979. A copy of the course description is attached.

Several project personnel were involved in activities of the ISES International Symposium in Atlanta during the week following the short course. Art Sales was in charge of a film program, other project personnel chaired sessions and aided in planning and implementation of various aspects of the ISES program.

Plans are underway for a regional solar resource atlas, with maps and tables of average available radiation and related meteorological parameters. Some examples of the types of data to be included in the Atlas are attached.

Task 3: Instrumentation and Monitoring Techniques Research

The permanent stands and equipment racks for the Portable monitoring unit are still under construction. A temporary set up of the unit in conjunction with the Peachtree Road Race on July 4, aided the Communicable

Disease Center in a study they were conducting on environmental stress and fatique.

The all-sky camera system is installed and is now undergoing tests.

The automatic sun photometer design is completed and system component acquisition is underway.

The automatic sunshine duration recorder using a NIP and on/off threshold detector has been constructed and will be installed next week.

SHORT COURSE DESCRIPTION

SOLAR RADIATION MEASUREMENT & APPLICATIONS

May 21-22, 1979

Georgia Institute of Technology
Continuing Education Courses

FACULTY

Drs. C. G. Justus, J. R. Williams and A. P. Sheppard are the academic administrators for the course. Dr. Justus is a professor in the Atmospheric Sciences Program of the School of Geophysical Sciences. He is the principal investigator of the D.O.E. sponsored Solar Energy Meteorological Research and Training Site program at Georgia Tech. Under this project instrumentation is used to measure a wide variety of solar radiation and related meteorological data. These continuous, well calibrated and quality controlled sets of solar radiation data, to be monitored over an extended period of time, will yield a research-grade solar radiation information data base for solar energy purposes.

Dr. Williams is associate dean of the College of Engineering and professor of mechanical engineering. He is author of *Solar Energy Technology and Applications*, Ann Arbor Science, 1974 and 1977, and is principal investigator of what is now the world's largest solar heated and air conditioned building and several other heating and cooling projects, and has responsibility for three Georgia Tech contracts on solar concentrators. He is also responsible for Georgia Tech's participation in two large solar total energy demonstration projects.

Dr. Sheppard is associate vice president of research at Georgia Tech and professor of electrical engineering. He has served as coordinator of the many

solar energy research projects at Georgia Tech and has spent some time at the CNRS Solar Furnace at Odeillo, France and is involved in solar energy applications to agriculture.

Mr. David L. Christensen, Research Associate, Center for Environmental and Energy Studies, University of Alabama at Huntsville, solar radiation instrumentation and applications.

Dr. G. W. Grams, Professor, School of Geophysical Sciences, Georgia Tech, physical principles of solar radiation and its transport through the atmosphere.

Dr. J. I. Craig, Associate Professor, Aerospace Engineering, Georgia Tech, solar instrumentation and environmental evaluation and design applications.

Dr. J. H. Schlag, Associate Professor, Electrical Engineering, Georgia Tech, solar tracking, recording and processing instrumentation.

Dr. J. I. Metcalf, Senior Research Scientist, Engineering Experiment Station, Georgia Tech, solar radiation transport, atmospheric effects.

COURSE TOPICS

Solar Radiation Characteristics. Descriptive aspects. The solar constant. Solar radiation at the earth's surface.

The Terrestrial Atmosphere. Effects on intensity and directional characteristics of radiation. Molecular and aerosol absorption and scattering. Effects of clouds.

Measurements of Solar Radiation Parameters. Average values and fluctuations. Geographical and seasonal effects.

Instrumentation. Types of instruments. Installation, operation and calibration. Data acquisition and quality control.

Available Solar Radiation Data. Survey of available insolation data, its acquisition and applications.

Applications. Use of solar radiation data in design of energy conversion systems and solar homes and buildings.

SOLAR RADIATION MEASUREMENT AND APPLICATIONS

This course is designed to familiarize the participant with the methods for measuring and utilizing solar radiation information. It will illustrate when and how existing solar radiation data bases may be used in certain engineering applications. For monitoring of solar radiation, the course covers various aspects of monitoring instrumentation, installation, operation, calibration, data acquisition, and processing.

To be offered the week prior to the International Solar Energy Society (ISES) Conference in Atlanta, and immediately before the Solar Heating and Cooling short course at Georgia Tech, this course offers an excellent opportunity to "get up to speed" on solar radiation measurement and applications techniques. It also offers an excellent opportunity to gain first hand knowledge of the numerous solar energy projects on and around the Georgia Tech campus, through tours of facilities during this short course and later in the week, prior to the ISES Conference.

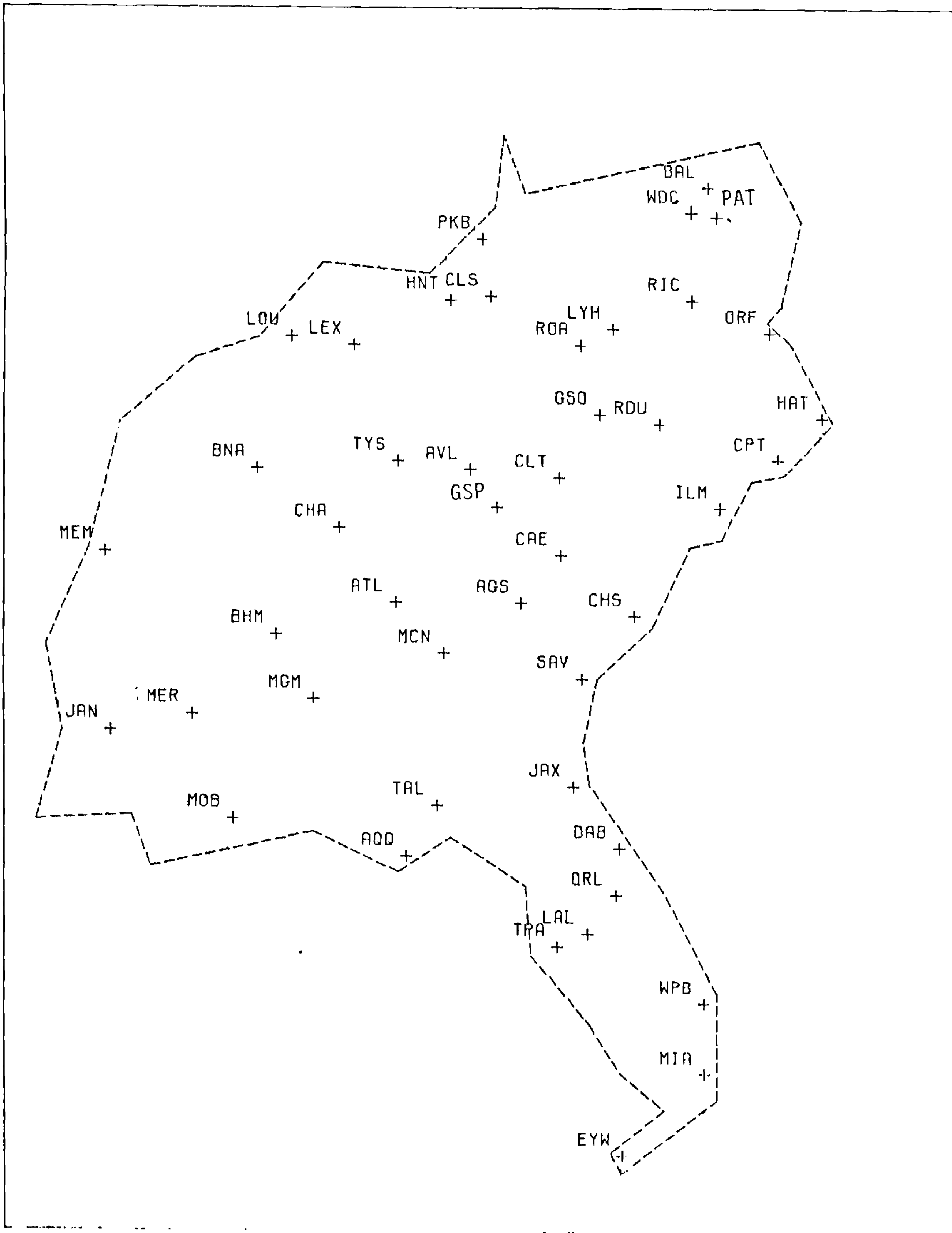
TOUR OF FACILITIES

A tour will be provided of the Solar Energy Meteorological Research and Training Site. This facility includes instrumentation for measurement of global, direct, and diffuse radiation, global on a tilted surface, global and diffuse spectral radiation, UV, IR, atmospheric turbidity, and many associated meteorological parameters.

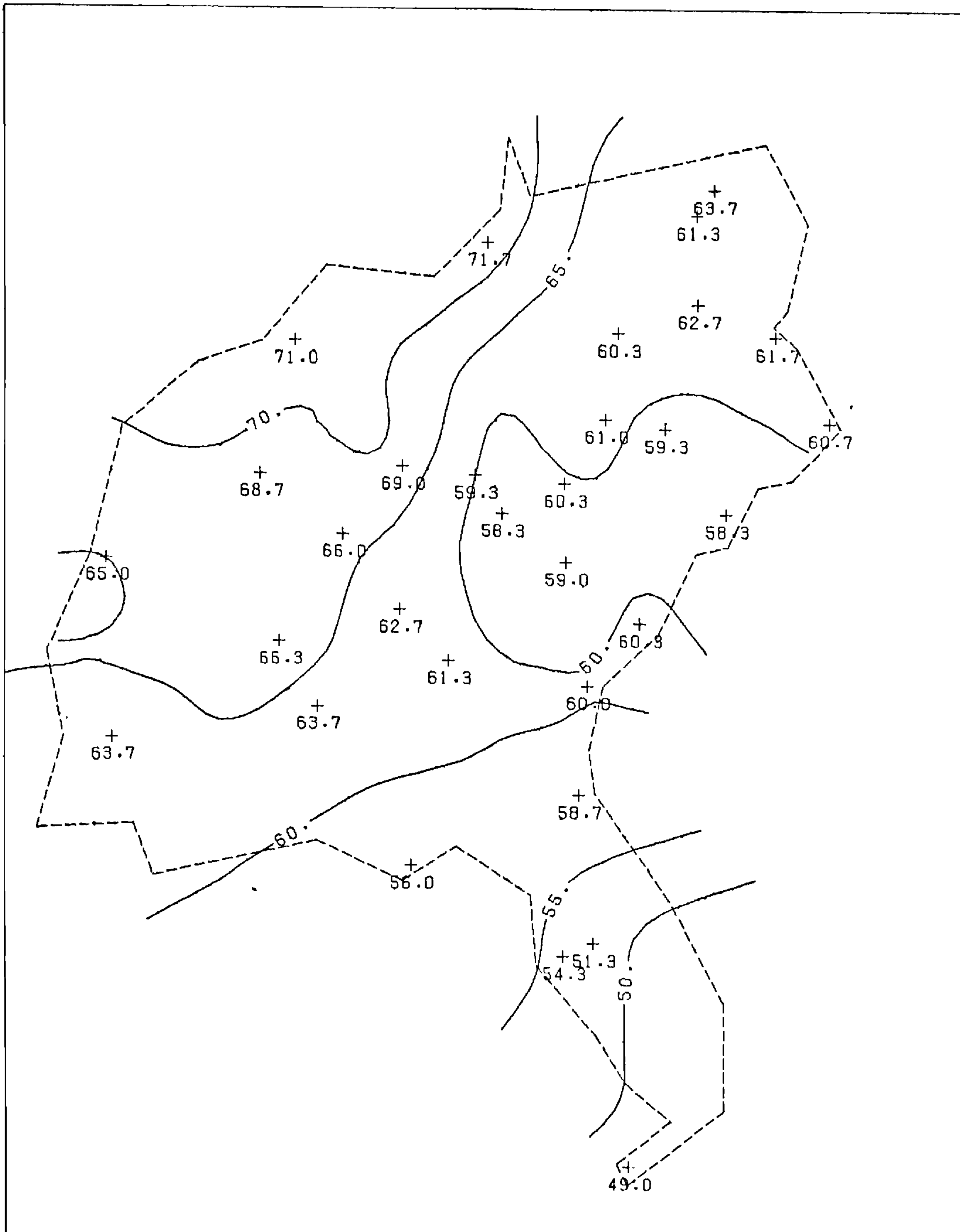
The Solar Energy Meteorological Research and Training Site program at Georgia Tech is one of eight regional centers around the country, sponsored

by DOE, for purposes of carrying out solar radiation monitoring, research, and training activities. During the tour, participants will get to see the various solar radiation monitoring instrumentation in action, and to use some of them in simple experiments to gain first hand knowledge of their operating characteristics and uses.

STATION CODES AND LOCATIONS



PERCENT SKY COVER WINTER NORM



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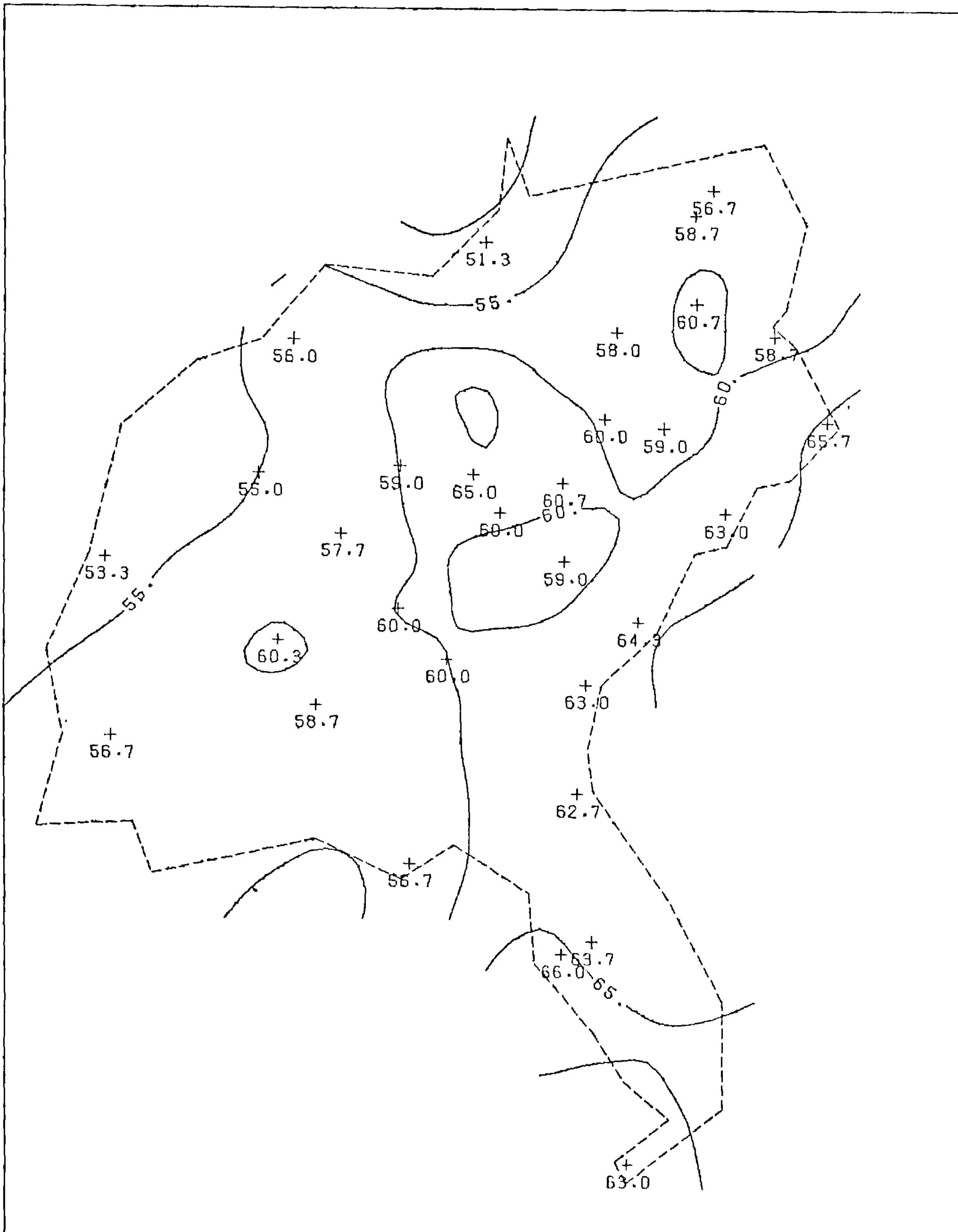

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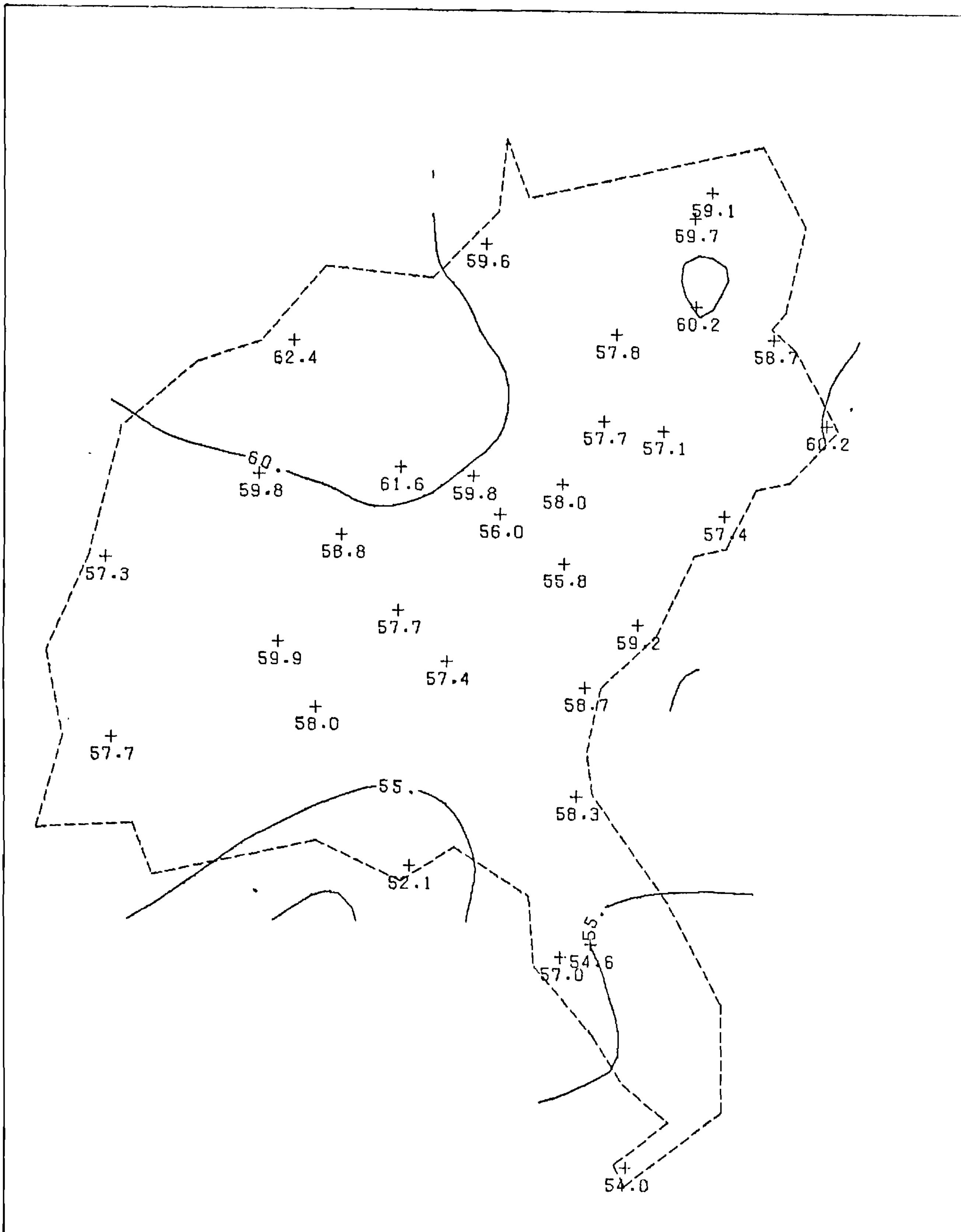

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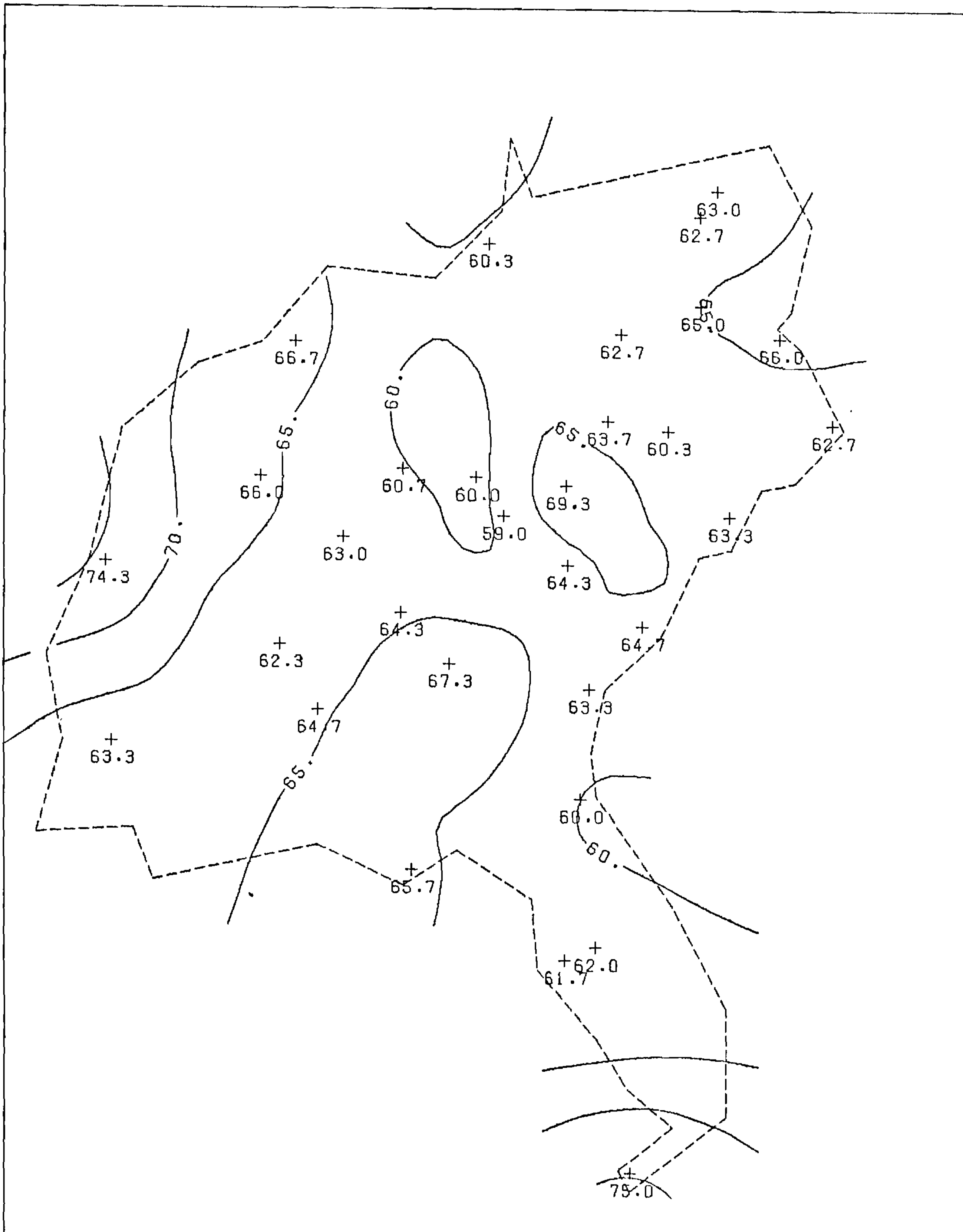

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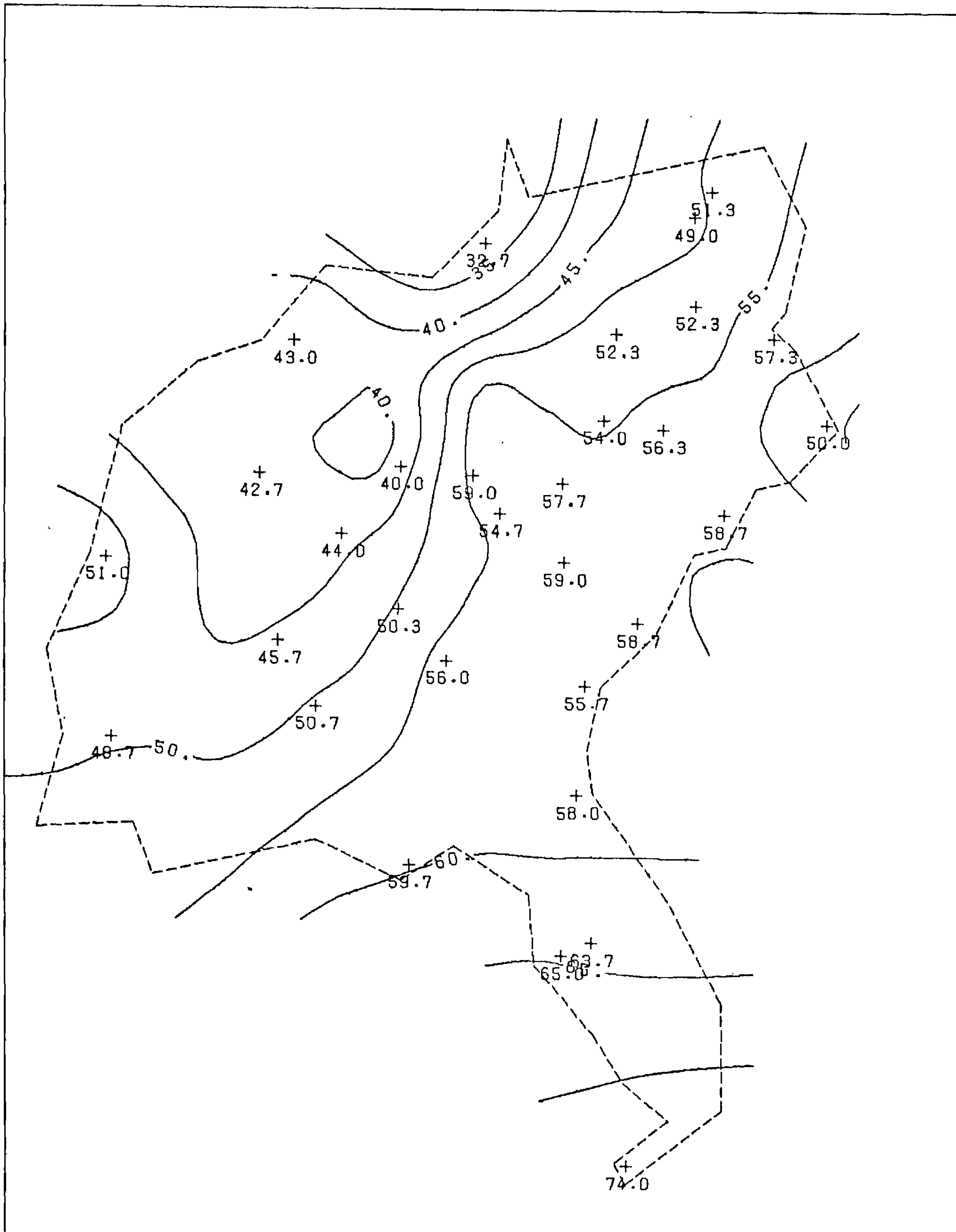
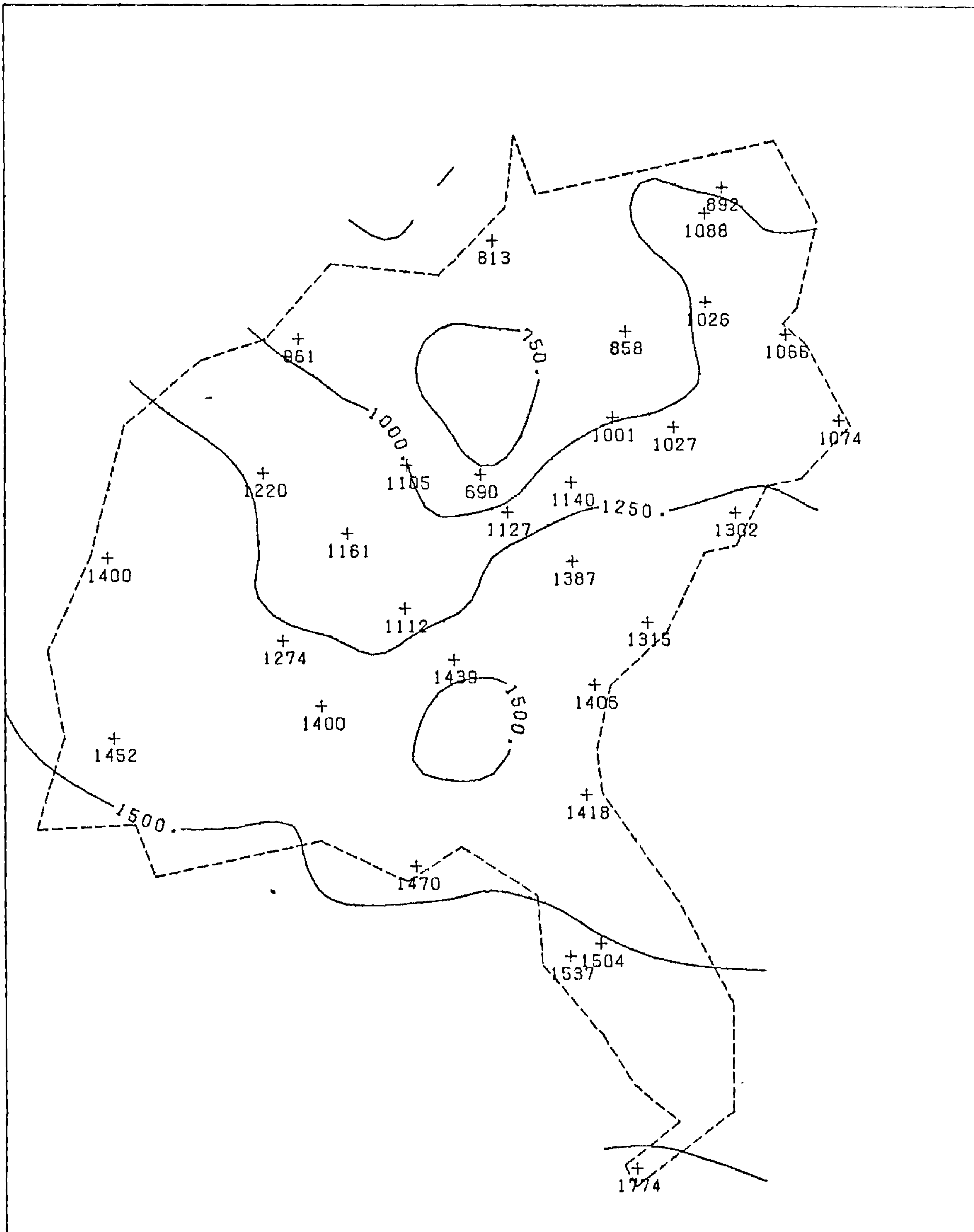
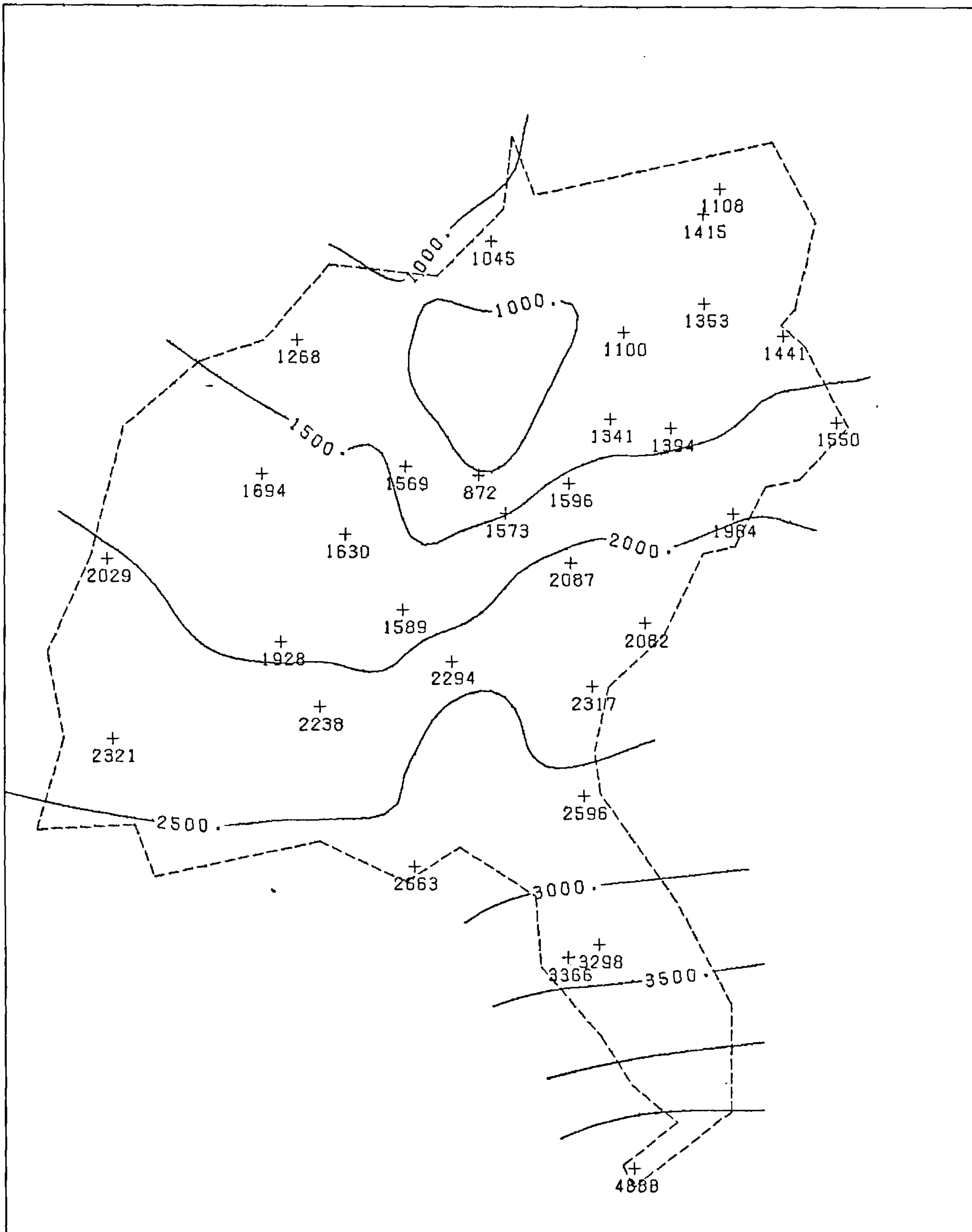


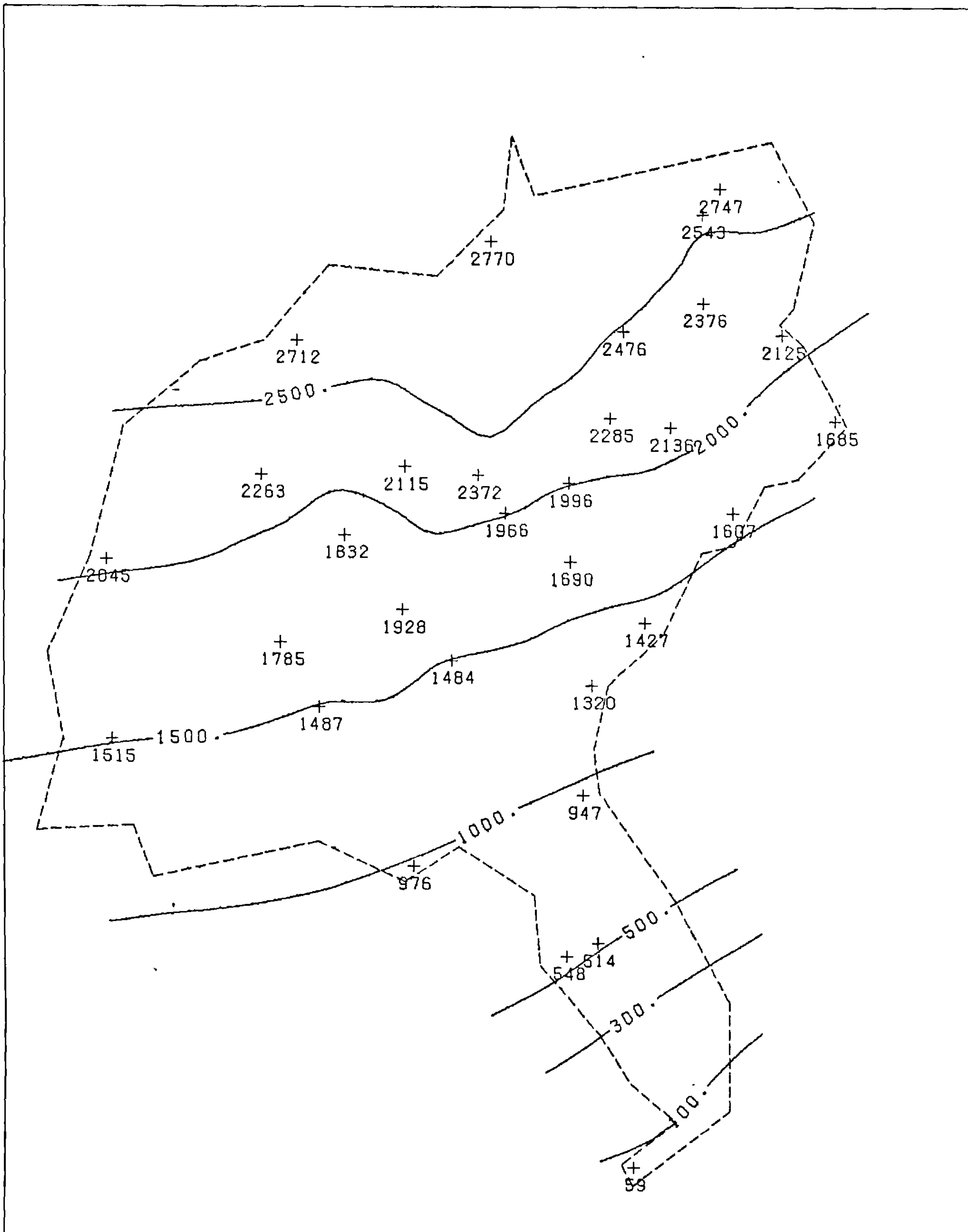
COOLING DEGREE DAYS SUMMER NORM



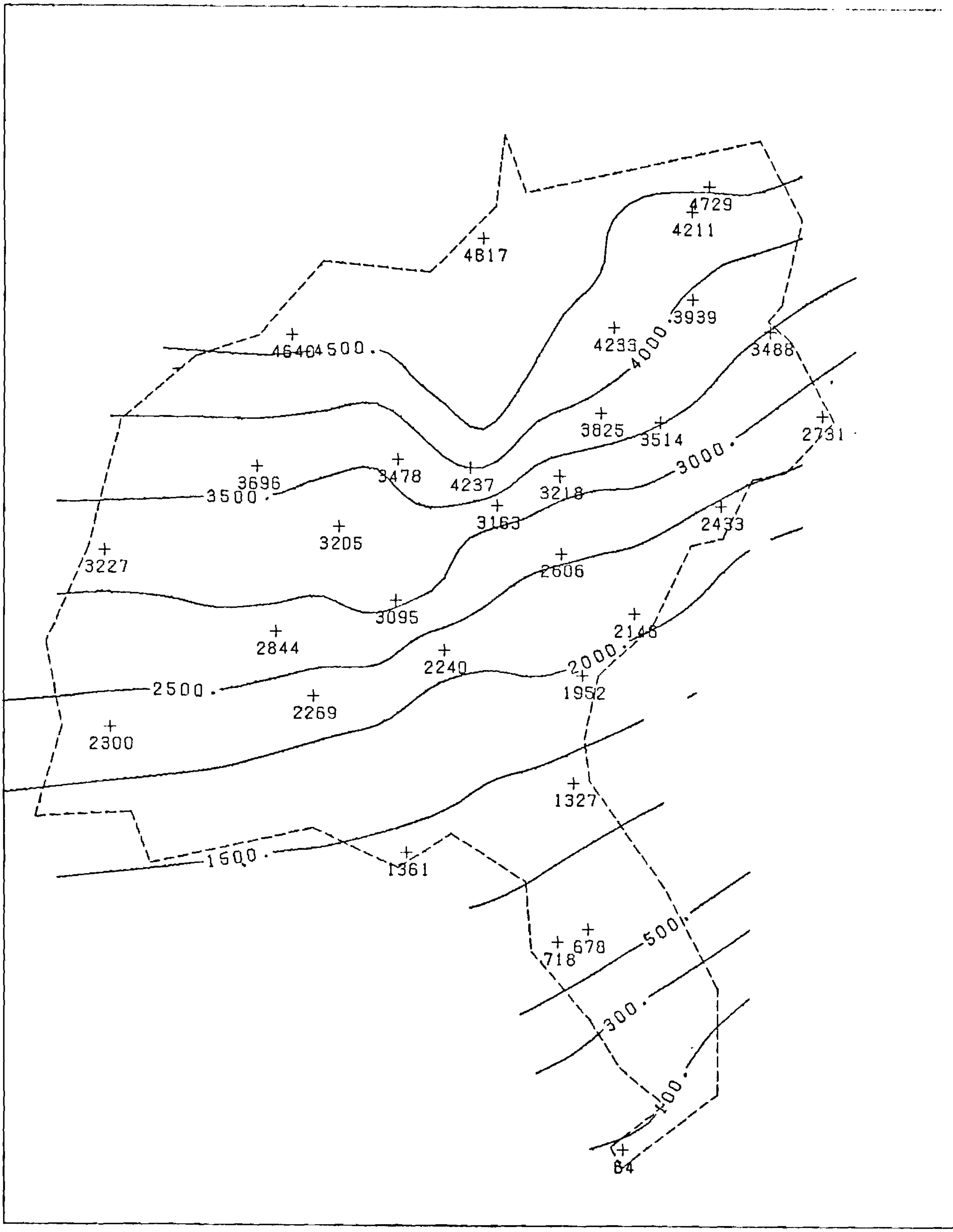
COOLING DEGREE DAYS ANNUAL NORM



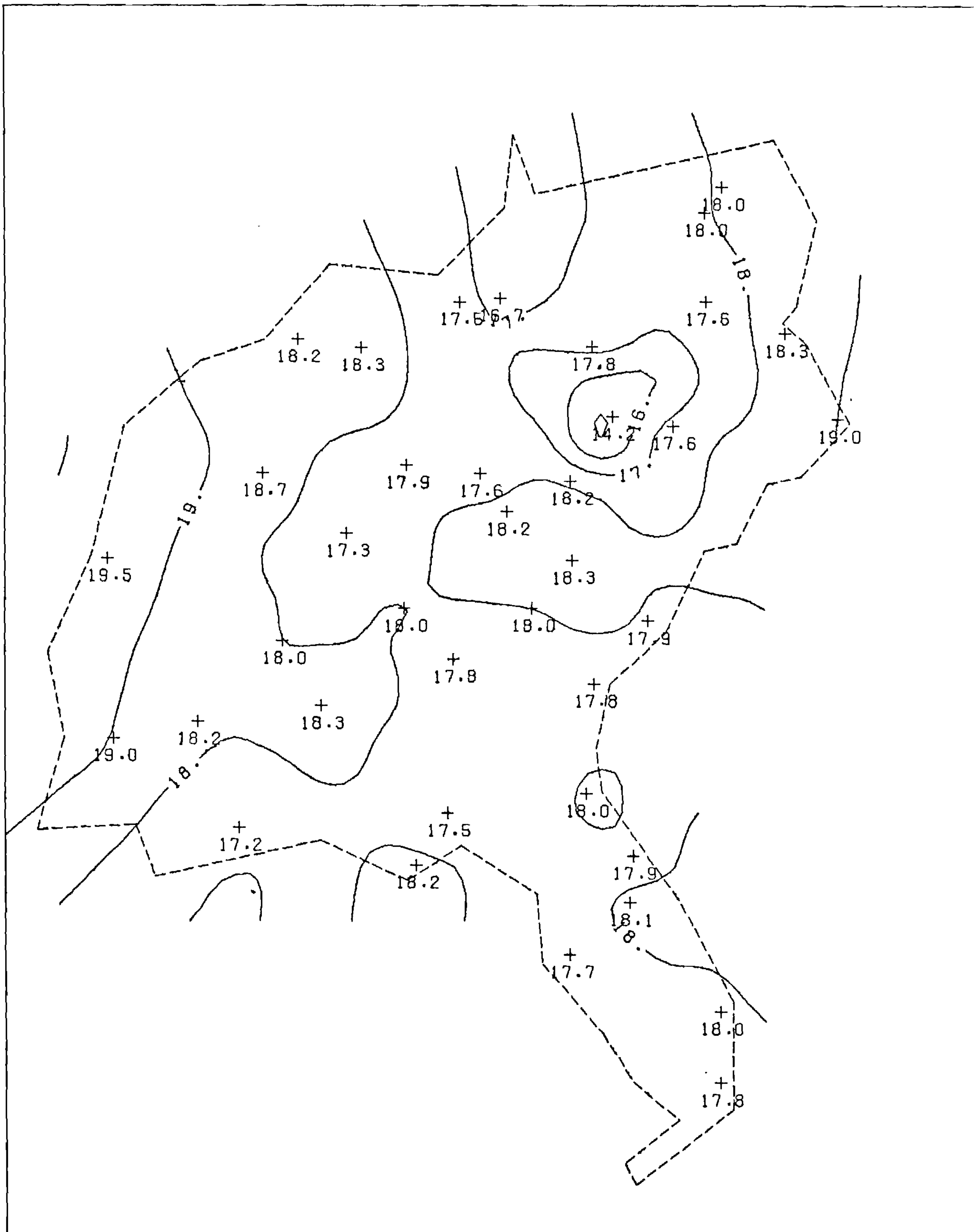
HEATING DEGREE DAYS WINTER NORM



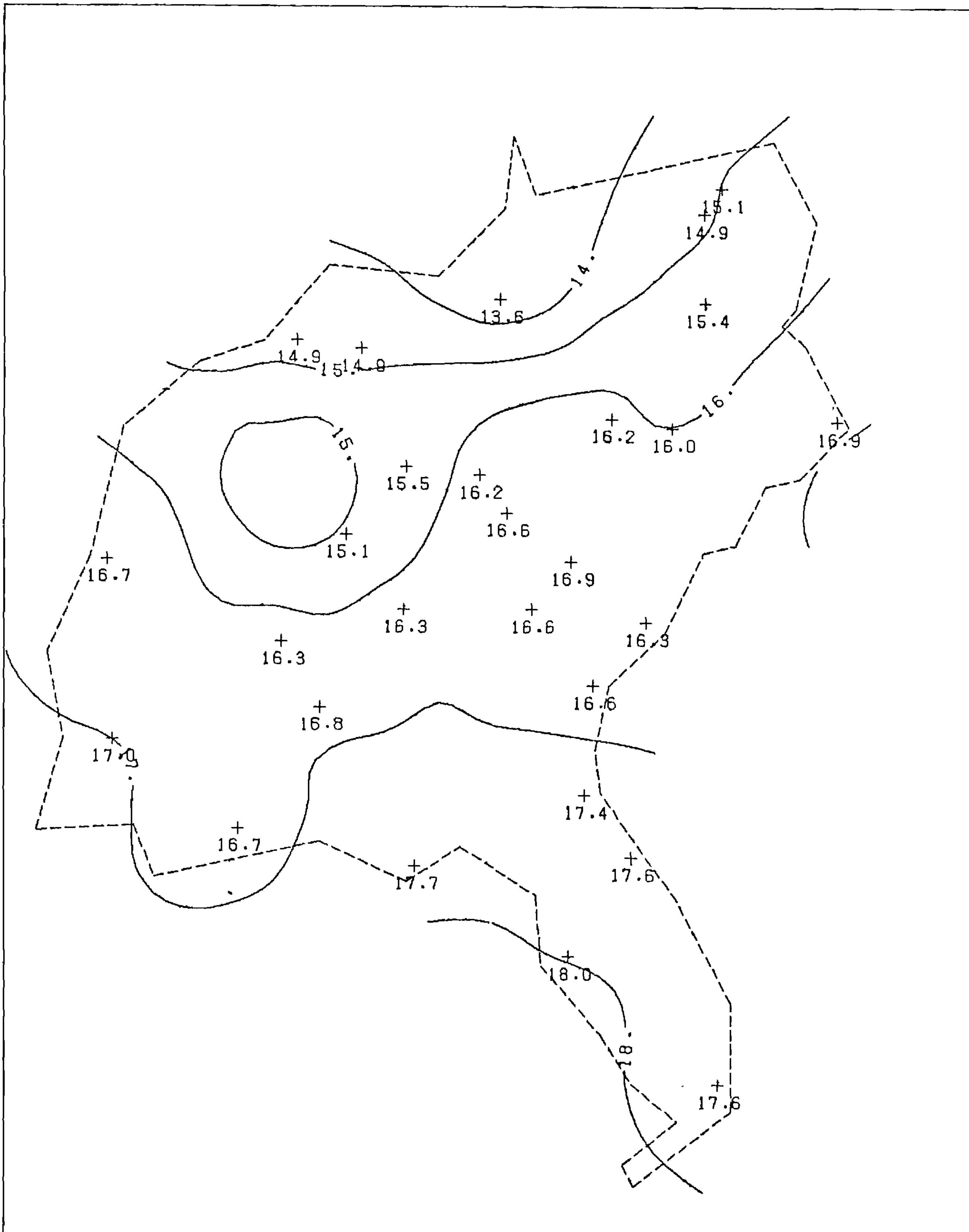
HEATING DEGREE DAYS ANNUAL NORM



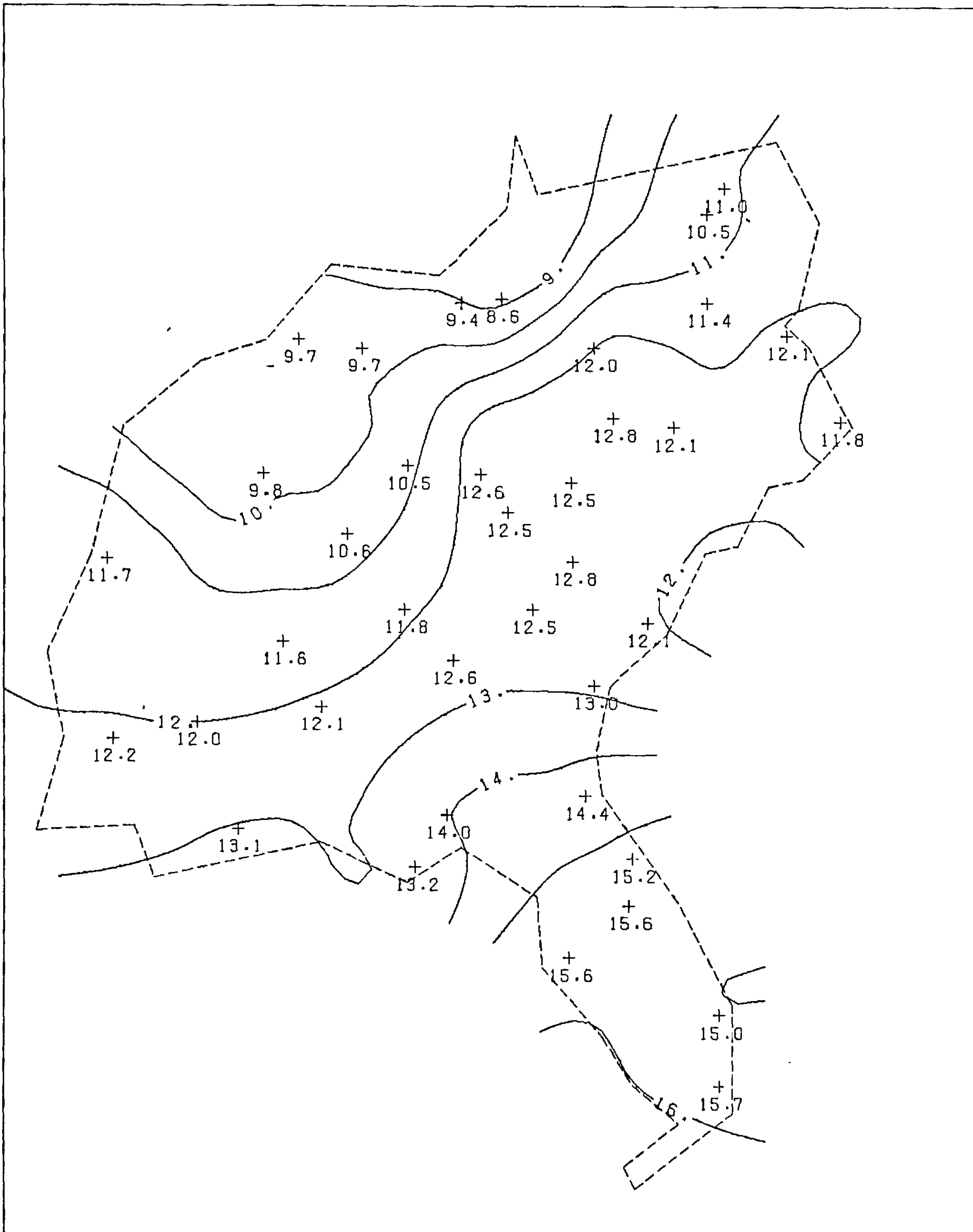
DAILY INSOLATION ON LATITUDE TILTED SFC. MJ/M^2 JULY AVG.

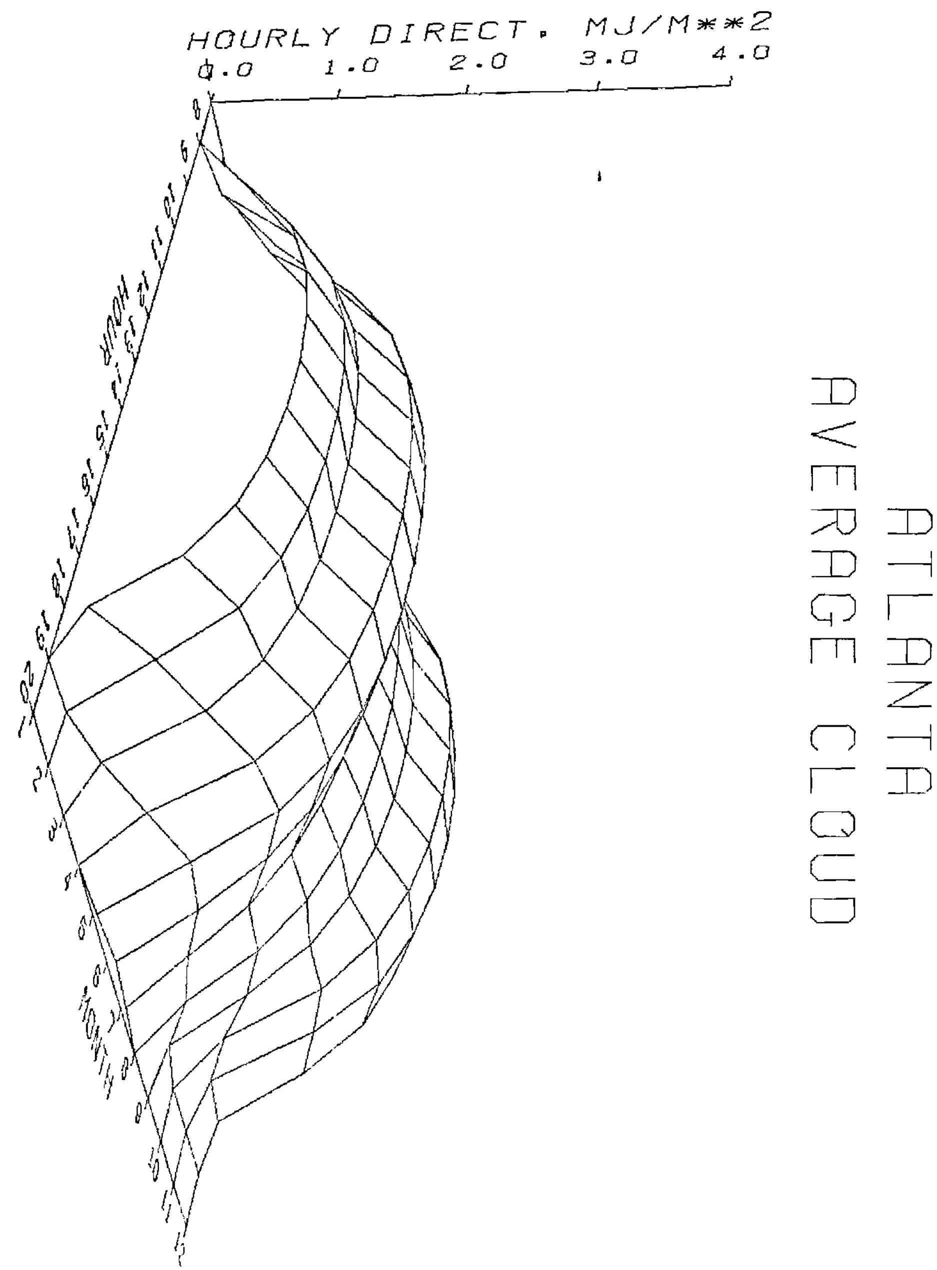


DAILY INSOLATION ON LATITUDE TILTED SFC. MJ/M^2 ANN AVG.



DAILY INSOLATION ON LATITUDE TILTED SFC. MJ/M^2 JANUARY AVG.





HOURLY DIRECT. MJ/M**2
0.0 1.0 2.0 3.0 4.0
HOUR
MONTH
ATLANTA
AVERAGE CLOUD

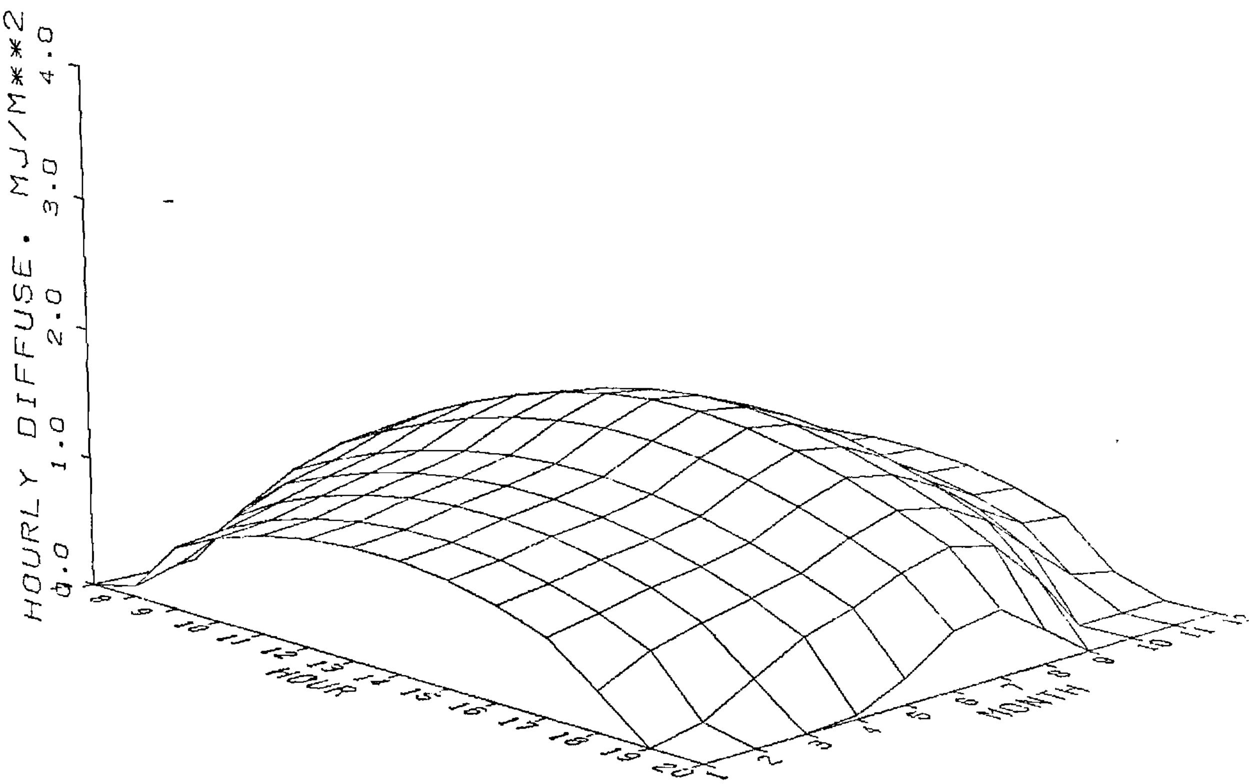
ATLANTA

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
7	0.000	0.000	.002	.218	.523	.423	.205	.113	.048	.007	0.000	0.000
8	.011	.090	.422	.950	1.115	.899	.617	.578	.517	.480	.282	.038
9	.455	.734	.978	1.349	1.421	1.181	.900	.927	.937	1.074	.968	.598
10	.902	1.123	1.212	1.555	1.591	1.349	1.075	1.136	1.170	1.367	1.315	1.020
11	1.097	1.300	1.332	1.667	1.688	1.449	1.188	1.260	1.300	1.518	1.480	1.199
12	1.169	1.386	1.392	1.725	1.740	1.504	1.248	1.328	1.368	1.590	1.555	1.282
13	1.224	1.421	1.416	1.746	1.757	1.524	1.267	1.355	1.390	1.609	1.574	1.307
14	1.213	1.415	1.410	1.733	1.743	1.512	1.258	1.344	1.372	1.578	1.543	1.286
15	1.155	1.369	1.373	1.685	1.696	1.467	1.215	1.293	1.308	1.490	1.450	1.209
16	1.023	1.263	1.294	1.588	1.696	1.380	1.131	1.194	1.165	1.312	1.255	1.042
17	.739	1.047	1.138	1.411	1.447	1.233	.990	1.024	.968	.967	.817	.652
18	.172	.550	.812	1.075	1.162	.987	.761	.739	.564	.298	.099	.062
19	0.000	.016	.166	.391	.614	.569	.402	.286	.065	0.000	0.000	0.000
20	0.000	0.000	0.000	.001	.032	.070	.040	.004	0.000	0.000	0.000	0.000

ATLANTA
AVERAGE CLOUD



ATLANTA

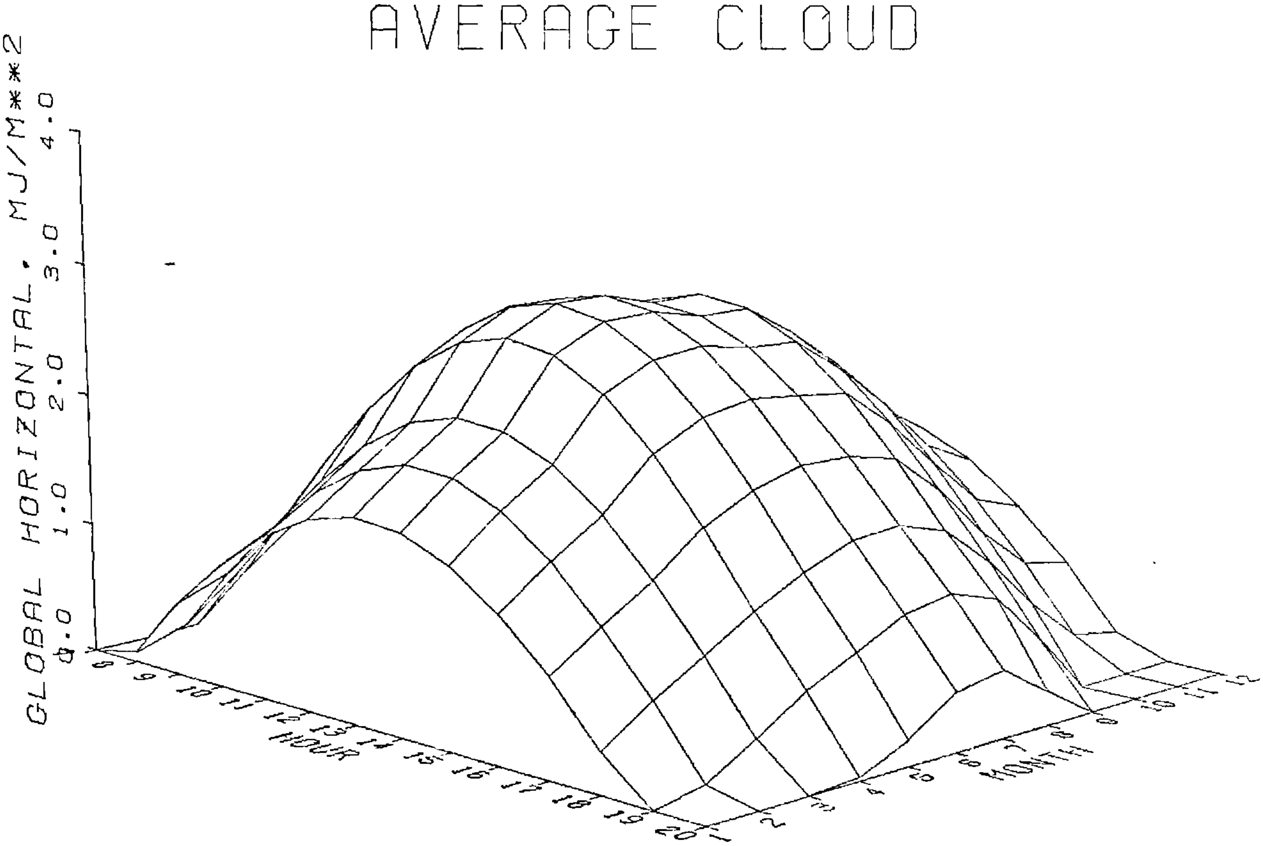
HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	1	2	3	4	5	6	7	8	9	10	11	12
7	0.000	0.000	.026	.353	.582	.719	.773	.646	.349	.108	0.000	0.009
8	.077	.205	.459	.635	.747	.895	.974	.913	.783	.580	.297	.122
9	.477	.540	.656	.789	.832	1.042	1.141	1.089	.962	.747	.556	.478
10	.648	.691	.793	.893	.999	1.162	1.277	1.231	1.102	.869	.678	.621
11	.751	.795	.891	.976	1.071	1.252	1.381	1.339	1.204	.955	.760	.716
12	.817	.862	.954	1.029	1.120	1.310	1.448	1.408	1.266	1.005	.808	.772
13	.846	.892	.982	1.049	1.139	1.332	1.477	1.437	1.289	1.019	.821	.792
14	.837	.887	.975	1.037	1.124	1.319	1.466	1.424	1.270	.996	.799	.776
15	.791	.847	.938	.992	1.078	1.270	1.416	1.371	1.211	.937	.744	.728
16	.706	.770	.857	.916	1.002	1.189	1.329	1.279	1.112	.842	.658	.631
17	.575	.655	.744	.810	.897	1.076	1.207	1.150	.976	.711	.518	.439
18	.297	.485	.589	.673	.765	.936	1.058	.988	.891	.494	.205	.180
19	0.000	.031	.290	.492	.604	.768	.870	.739	.446	0.000	0.000	0.000
20	0.000	0.000	0.000	.039	.191	.440	.504	.252	0.000	0.000	0.000	0.000

MONTH

ATLANTA
AVERAGE CLOUD



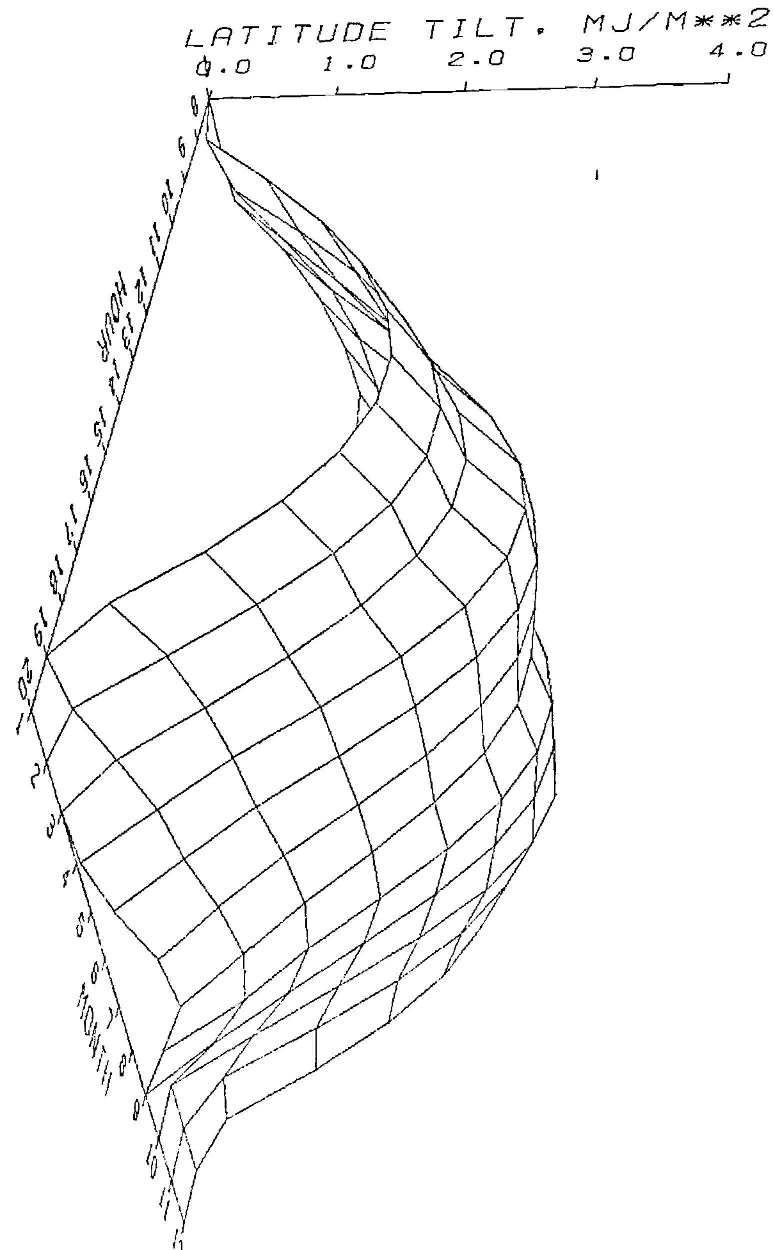
ATLANTA

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	1	2	3	4	5	6	7	8	9	10	11	12
7	0.000	0.000	.026	.381	.688	.811	.814	.663	.358	.109	0.000	0.000
8	.078	.212	.527	.911	1.167	1.258	1.208	1.098	.916	.668	.321	.124
9	.350	.700	.984	1.480	1.682	1.728	1.640	1.560	1.377	1.128	.794	.575
10	.921	1.124	1.417	1.909	2.145	2.161	2.050	2.002	1.819	1.575	1.204	.944
11	1.282	1.480	1.768	2.289	2.510	2.507	2.385	2.368	2.172	1.936	1.528	1.341
12	1.445	1.728	2.007	2.533	2.744	2.795	2.612	2.606	2.401	2.142	1.725	1.438
13	1.540	1.847	2.117	2.687	2.831	2.826	2.711	2.710	2.484	2.208	1.701	1.502
14	1.511	1.823	2.090	2.576	2.768	2.772	2.674	2.666	2.414	2.108	1.690	1.444
15	1.359	1.672	1.928	2.362	2.545	2.579	2.508	2.476	2.198	1.852	1.460	1.268
16	1.096	1.392	1.642	2.010	2.195	2.261	2.214	2.158	1.854	1.473	1.111	.974
17	.750	1.012	1.255	1.552	1.741	1.847	1.838	1.748	1.419	1.013	.689	.609
18	.314	.581	.804	1.035	1.229	1.377	1.400	1.280	.955	.539	.212	.142
19	0.000	.082	.307	.555	.735	.917	.979	.851	.456	0.000	0.000	0.000
20	0.000	0.000	0.000	.030	.193	.448	.509	.253	0.000	0.000	0.000	0.000

MONTH



ATLANTA

AVERAGE CLOUD

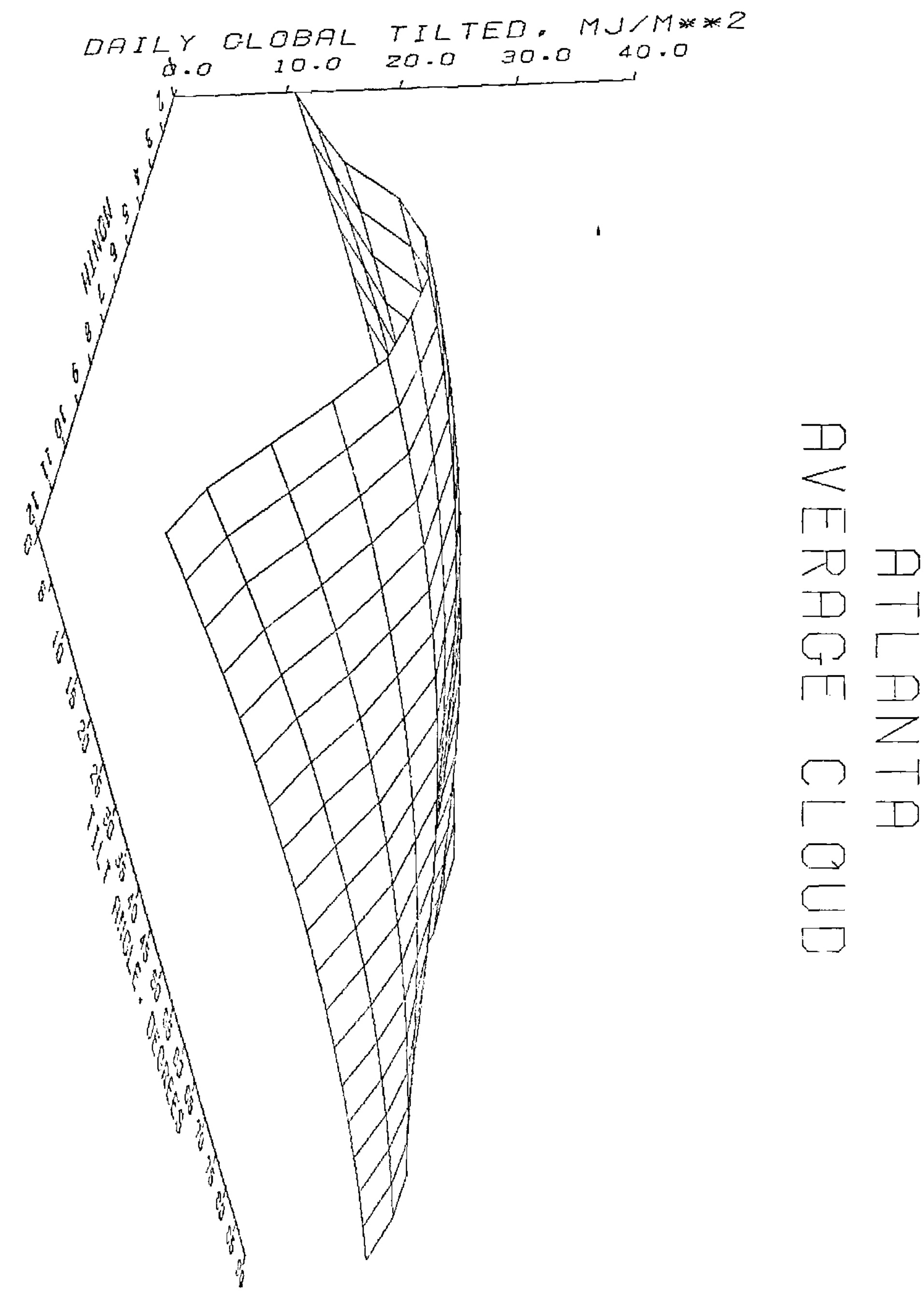
ATLANTA

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
7	0.000	0.000	.024	.332	.542	.658	.706	.598	.323	.100	0.000	0.000
8	.074	.210	.514	.807	.949	1.013	1.014	.962	.856	.635	.350	.124
9	.635	.802	1.024	1.346	1.464	1.467	1.422	1.409	1.344	1.249	.999	.713
10	1.143	1.330	1.512	1.866	1.954	1.909	1.833	1.854	1.825	1.731	1.532	1.226
11	1.534	1.756	1.909	2.233	2.349	2.273	2.179	2.247	2.216	2.194	1.932	1.602
12	1.793	2.049	2.180	2.565	2.605	2.516	2.418	2.509	2.471	2.447	2.172	1.839
13	1.903	2.183	2.305	2.675	2.701	2.614	2.523	2.621	2.564	2.518	2.239	1.928
14	1.878	2.166	2.274	2.608	2.626	2.557	2.484	2.578	2.406	2.402	2.129	1.858
15	1.689	1.983	2.091	2.369	2.387	2.349	2.303	2.368	2.245	2.107	1.848	1.629
16	1.365	1.651	1.767	1.978	2.007	2.014	2.001	2.029	1.865	1.660	1.414	1.264
17	.917	1.193	1.329	1.477	1.526	1.586	1.613	1.596	1.383	1.110	.852	.763
18	.385	.646	.821	.932	1.009	1.127	1.193	1.133	.896	.536	.217	.147
19	0.000	.077	.291	.482	.578	.733	.828	.749	.415	0.000	0.000	0.000
20	0.000	0.000	0.000	.023	.171	.394	.457	.231	0.000	0.000	0.000	0.000

MONTH


ATLANTA
AVERAGE CLOUD
DAILY GLOBAL TILTED, MJ/M**2
0.0
10.0
20.0
30.0
40.0
MONTH
TILT ANGLE, DEGREES

ATLANTA

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

MONTH	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
1	10.80	11.36	11.86	12.31	12.70	13.03	13.29	13.49	13.62	13.67	13.66	13.58	13.43	13.21	12.93	12.58	12.16	11.70	11.17
2	13.66	14.26	14.79	15.26	15.64	15.94	16.17	16.31	16.36	16.33	16.22	16.02	15.74	15.38	14.95	14.44	13.86	13.21	12.50
3	16.87	17.34	17.72	18.02	18.23	18.34	18.37	18.30	18.14	17.89	17.55	17.13	16.62	16.04	15.38	14.65	13.85	13.00	12.10
4	22.21	22.53	22.74	22.83	22.80	22.66	22.40	22.03	21.55	20.96	20.27	19.49	18.61	17.65	16.61	15.50	14.33	13.12	11.85
5	25.16	25.24	25.20	25.03	24.73	24.32	23.78	23.12	22.36	21.49	20.53	19.47	18.33	17.12	15.84	14.50	13.13	11.71	10.28
6	26.22	26.19	26.08	25.75	25.35	24.83	24.20	23.46	22.62	21.68	20.66	19.55	18.37	17.12	15.82	14.48	13.10	11.70	10.29
7	25.58	25.58	25.42	25.20	24.87	24.43	23.88	23.24	22.50	21.67	20.76	19,77	18.71	17.59	16.42	15.20	13.96	12.68	11.39
8	24.43	24.58	24.61	24.54	24.36	24.06	23.67	23.16	22.56	21.87	21.08	20.21	19.27	18.25	17.17	16.04	14.86	13.65	12.41
9	20.82	21.16	21.41	21.57	21.62	21.57	21.42	21.18	20.83	20.40	19.87	19,25	18.56	17.78	16.94	16.03	15.07	14.05	12.99
10	16.73	17.33	17.85	18.29	18.63	18.87	19.02	19.08	19.03	18.89	18.66	18.33	17.91	17.40	16.80	16.13	15.38	14.56	13.68
11	12.52	13.22	13.87	14.44	14.94	15.36	15.70	15.95	16.12	16.20	16.20	16.10	15.92	15.66	15.31	14.87	14.37	13.78	13.13
12	10.25	10.86	11.42	11.92	12.36	12.75	13.06	13.31	13.49	13.60	13.63	13.60	13.49	13.31	13.06	12.74	12.36	11.91	11.41

TILT ANGLE (DEGREES)

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

SCHOOL OF AEROSPACE ENGINEERING

DANIEL GUGGENHEIM SCHOOL OF AERONAUTICS

404-894-3000

27 July 1979

Mr. E. J. Ney
GSTEP
Georgia Power Company
P. O. Box 4545
Atlanta, GA 30302

Subject: Met Station Monthly Letter Technical Progress Report, July 1979

Dear Ed:

Operation of the met station has proceeded without significant problems during July. Specific aspects of the month's activities are summarized below:

1. No power outages or equipment malfunctions have been reported during July and a complete data record should be available shortly.

2. Available data from June 1979 have been processed and the daily summary is attached. The summary now includes columns for three recently installed Georgia Tech instruments (rain gage, net radiometer, and UV pyranometer). The net radiometer was installed on 5 July 1979 and data will begin to appear in the next monthly summary. No data was obtained prior to 11 June because an incorrect setting limited scanning to only six channels. This has been corrected and should not recur. Recovery of missing data by substitution of records from the campus station should be possible.

3. One of the pyrheliometers (16157E6) was exchanged with a recently calibrated sensor (16156E6) on 18 July 1979. It will be sent to Sandia for post-deployment calibration, and when returned it will be retained at Tech to provide a spare allowing future calibration to be accomplished on campus by comparison with an active-cavity pyrheliometer as well as a secondary standard pyrheliometer. Other equipment changes during the month involved installation of the net radiometer on 5 July and installation of an RG630 filter on the spectral pyrheliometer on 27 July. Henceforth the SP-DIR channel will record IR-filtered beam radiation.

4. Problems with tracking accuracy with the NIP's continued to be essentially alleviated. Tracking of the diffuse pyranometer (a Georgia Tech instrument) continues to be somewhat of a problem but the instrument is of secondary importance. A new drive for the diffuse pyranometer was installed in June accounting for some missing data.

5. Graphical daily plots of all radiation data obtained since October 1978 have been prepared with the Versatec plotter to aid in inspecting the data for quality control. A quality-control algorithm is currently under development to check all data for consistency and completeness, as well as physical and statistical reliability.

6. The humidity sensor remains unreliable. These data should be of value both in plant simulation and solar modeling; consequently, procurement and installation of the new instrument with Li C cell should be expedited.

Sincerely,

Sheldon M. Jeter
Research Engineer

SMF/ed

cc: Craig, Phan, Hill, J. Justus

Attachment: Monthly Summary

SHENANDOAH MET STATION DAILY TOTALS

DY	PD	WD	WS	RH	T(C)	KPA	DIR-1	DIR-2	SP-DIR	GLOBE	DIFUS	TILT	SP-GLO	NET-R	RAIN	UV
11	54	90.	2.6	10.	21.2	98.5	25434.	27955.	26117.	23464.	*.	20580.	13594.	*.	0.0	869.9
12	96	117.	1.0	27.	19.5	98.9	34764.	38035.	35647.	30427.	*.	25853.	17639.	*.	.1	1103.8
13	96	139.	.8	42.	20.3	99.1	27496.	28366.	27565.	27073.	*.	22961.	15617.	*.	.1	990.5
14	96	133.	1.5	42.	19.6	99.4	19959.	19436.	19339.	24738.	*.	21122.	14290.	*.	.1	906.3
15	96	71.	1.5	35.	19.0	99.3	11948.	11542.	11402.	22997.	22011.	19923.	12944.	*.	.2	888.9
16	96	150.	.6	48.	19.5	98.8	9612.	9219.	9234.	19689.	18826.	17312.	10954.	*.	.2	801.9
17	96	228.	.6	51.	22.1	98.7	14593.	14119.	14140.	24496.	33457.	21295.	14009.	*.	.2	911.3
18	96	261.	.5	51.	24.5	99.0	21795.	21380.	21331.	26726.	16069.	22978.	15320.	*.	0.0	969.9
19	96	230.	.3	58.	25.0	99.2	14410.	14438.	14148.	22438.	21301.	19285.	12814.	*.	.1	845.8
20	95	113.	1.8	80.	22.8	99.4	4955.	4973.	4681.	16941.	13262.	14583.	9463.	*.	0.0	676.1
21	96	156.	1.3	81.	23.2	99.3	2742.	2801.	2469.	18425.	15364.	15964.	10312.	*.	0.0	735.0
22	96	224.	.8	67.	24.2	99.0	22257.	22091.	21759.	26523.	10228.	22646.	15099.	*.	0.0	999.7
23	95	205.	1.3	59.	24.3	98.9	15597.	15593.	15281.	21969.	10987.	18569.	12285.	*.	0.0	869.7
24	96	218.	1.2	91.	22.6	98.8	5029.	4946.	4692.	14144.	10603.	11855.	7751.	*.	0.0	605.6
25	96	118.	1.2	104.	18.5	99.1	-15.	-119.	-414.	7626.	8471.	6586.	3819.	*.	0.0	384.6
26	96	82.	2.0	53.	19.8	99.5	1857.	1741.	1454.	15575.	12818.	13655.	8426.	*.	.1	663.6
27	96	58.	1.2	62.	20.3	99.4	10972.	10779.	10446.	21367.	12196.	18542.	11916.	*.	.2	878.1
28	96	151.	.4	65.	20.4	99.2	10064.	9910.	9641.	20624.	11915.	17945.	11546.	*.	.1	845.8
29	96	207.	1.1	57.	22.3	98.7	11926.	11810.	11523.	22503.	[illegible]	[illegible]	12777.	*.	0.0	865.6
30	96	237.	1.8	55.	24.3	98.3	25121.	24806.	24533.	27128.	7093.	25529.	15420.	*.	0.0	1032.4
OAVG:		159.	1.2	57.	21.7	99.0	14526.	14691.	14249.	21744.	14219.	18723.	12300.	*.	.1	842.2
SIG:		62.	.6	22.	2.1	.3	9501.	10098.	9712.	5319.	4742.	4535.	3227.	*.	.1	165.5

EOI. 0 FILES. 1 RECS. 285 WORDS.

/

RM ERDA 536
30/76)

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

CONTRACT MANAGEMENT SUMMARY REPORT

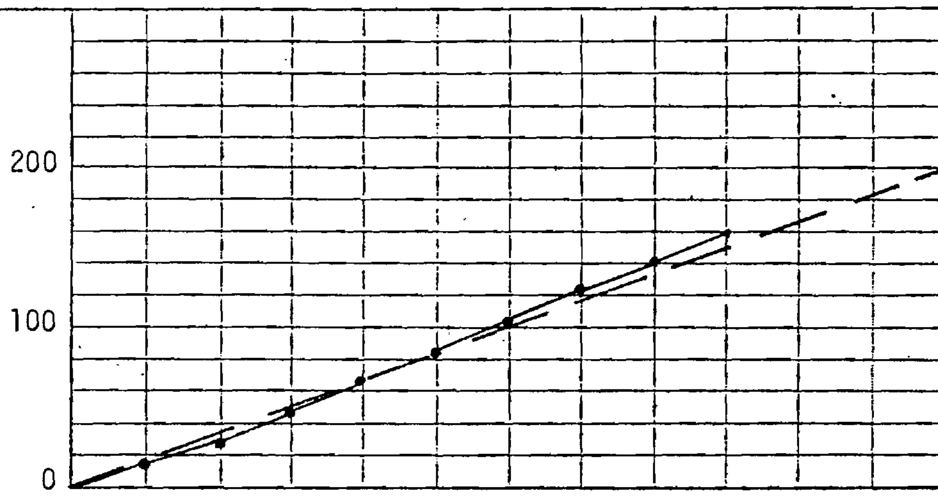
Contract Identification Program for Solar Energy Meteorological Research and Training Site (Region 3)	2. Reporting Period 4/1/79 through 6/30/79	3. Contract Number EG-77-G-05-5604
Contractor (name and address) Georgia Institute of Technology, Atlanta, Georgia 30332		5. Contract Start Date 9/30/77
		6. Contract Completion Date 9/29/79

Months	O	N	D	J	F	M	A	M	J	J	A	S	8. FY 79

Cost Status

Dollars
X
1000

Legend:
-----Planned & Approved
_____Actual
.....Contractors Latest Estimate



Accrued Costs		O	N	D	J	F	M	A	M	J	J	A	S
	b. Planned	17	33	50	67	83	100	117	133	150			
	c. Actual	15	30	44	65	85	106	124	141	159			
	d. Variance	2	3	6	2	2	6	7	8	9			

e. Actual Costs Prior FYs: $200,000

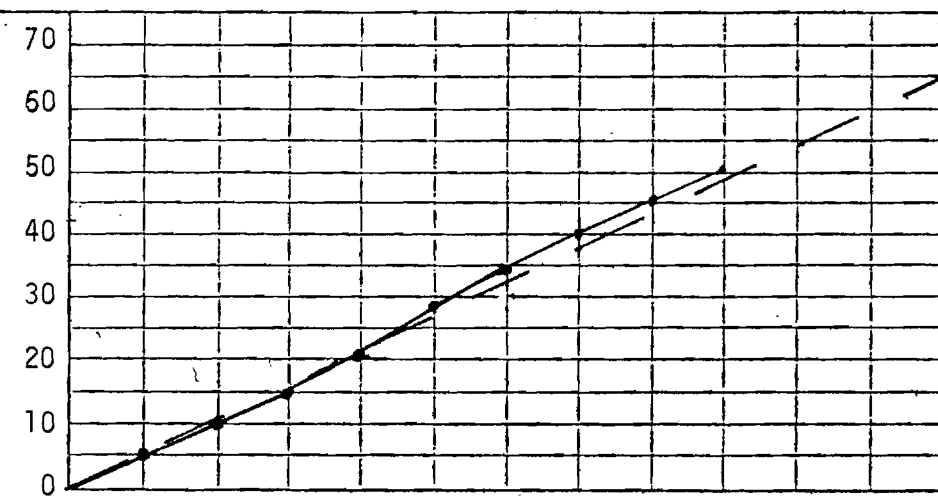
f. Planned Costs Prior FYs: $200,000

g. Total Projected Accrued Costs for Contract: $400,000

h. Total Contract Value: $400,000

Manpower Status

Man Months
X
1



Manpower		O	N	D	J	F	M	A	M	J	J	A	S
	b. Planned	5	10	16	22	27	33	38	44	49			
	c. Actual	5	10	15	21	28	34	40	45	51			
	d. Variance	0	0	1	1	-1	-1	-2	-1	-2			

e. ~~Actual~~ Manpower ~~Prior~~ FYs: 65 man months

f. Planned Manpower Prior FYs: 65 man months

g. Total Projected. Manpower for Contract: 59 man months

h. Total Contract Manpower: 59 man months

Major Milestone Status

See attached Detailed Milestone Chart.

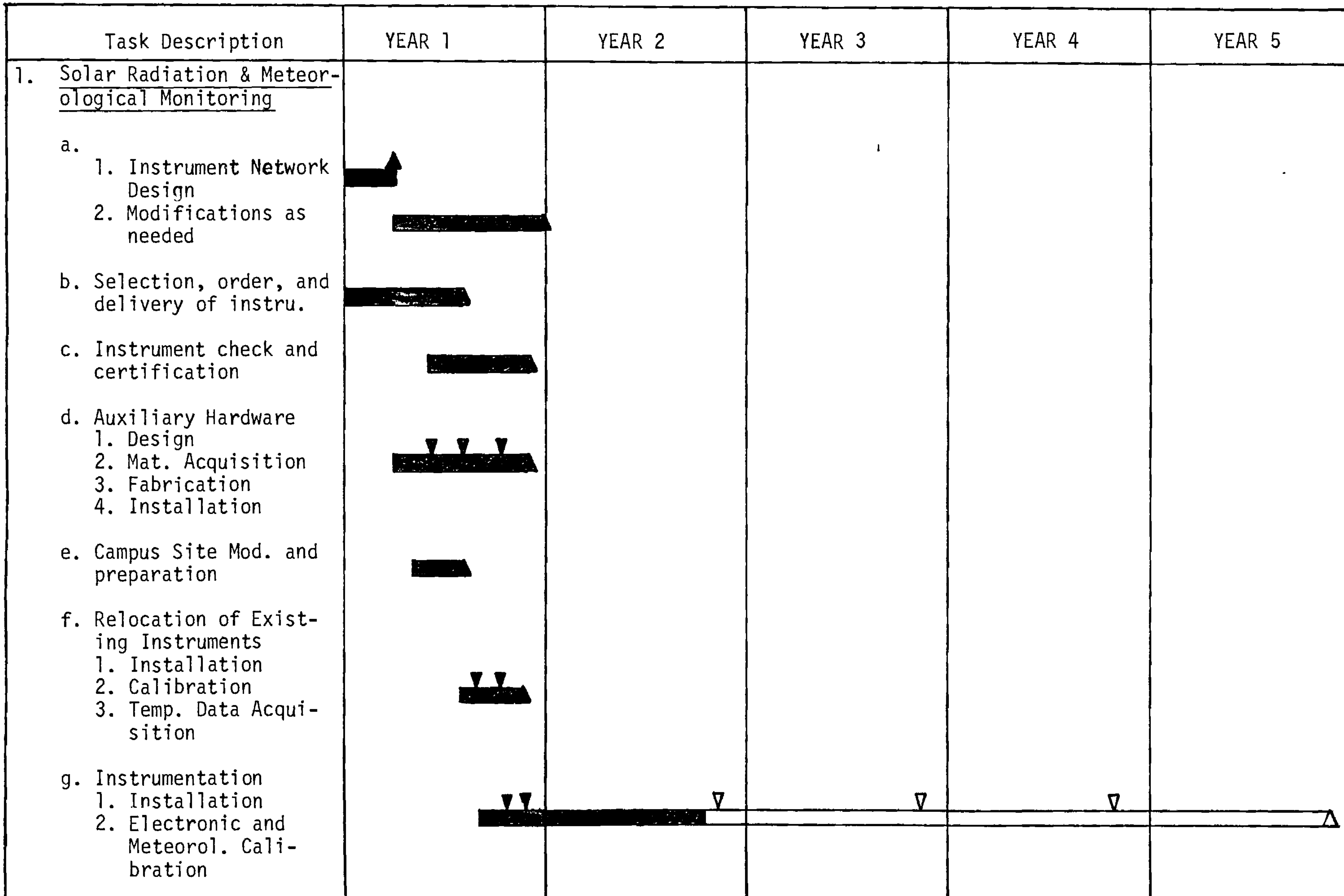
Remarks

Signature of Contractor's Project Manager and Date

[signature] 8/23/79

14. Signature of Government Technical Representative and Date

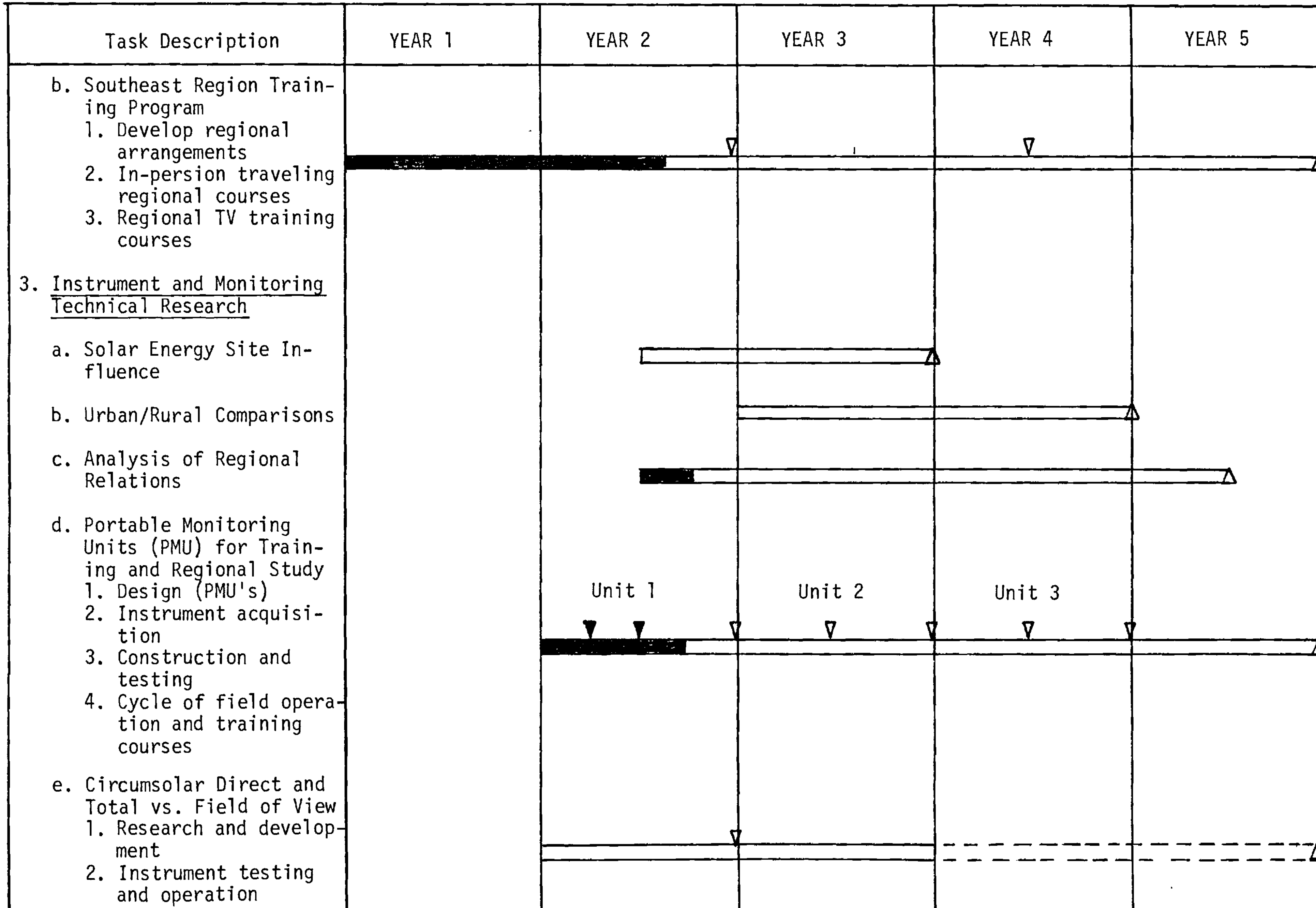
Milestone Chart



Milestone Chart (Cont'd.)

Task Description	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
h. Campus Site Monitor					
i. Shenandoah Monitor					
j. Analytical Software 1. Standardization 2. Development 3. Verification 4. Utilization 5. Modifications as needed					
k. Radiation Sensor Calibration					
l. Certification of Standard Radiation Instruments					
m. Data Transfer 1. National Climatic Center 2. Ga. Tech Files					
2. <u>Regional Training Program</u>					
a. On-campus and area program (including direct TV link) 1. Development 2. Operation					

Milestone Chart (Cont'd)



Milestone Chart (cont'd)

Task Description	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
f. Automatic Filter holder for NIP Spectral Data 1. Research and development 2. Testing and operation					
g. Automatic cloud cover camera 1. Research and development 2. Testing and operation					
4. <u>Reports and Review Meetings</u>					
Technical Status Reports					
Review Meeting					
Technical Progress Reports					

Annual Progress Report

ORO/5604–80/1

Report Period– October 1, 1978–September 30, 1979

PROGRAM FOR SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE (REGION 3)

By

John B. Kline, Amir S. Mikhail,
William L. Meyer, and C. G. Justus

Prepared for

THE UNITED STATES DEPARTMENT OF ENERGY

DIVISION OF DISTRIBUTED SOLAR TECHNOLOGY

Under

GRANT NO. EG–77–G–05–5604

PROJECT NO. E–16–C01

January, 1980

GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL OF AEROSPACE ENGINEERING

ATLANTA, GEORGIA 30332

1980

ORO/5604-80/1

PROGRAM FOR SOLAR ENERGY METEOROLOGICAL RESEARCH AND TRAINING SITE (REGION 3)

Annual Progress Report
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UNDER GRANT EG-77-G-05-5604

Georgia Tech Project E-16-C01

ABSTRACT

As the use of an interest in solar energy increases, there is as well an increase in demand for information concerning its availability in a particular location. In order to properly access the design necessities for any use, one must be able to account for the energy demands for the area as well as important climatological variables that affect the amount of solar energy available.

This solar atlas shows graphically and in tabular form how the insolation and some climatological parameters vary with season, location, and in some cases, time of day. The close connection between solar energy availability and the meteorology is shown in many of the contour maps, and the 3-D projections plots display well the effect of cloudiness, and tilt angle of a flat surface.

Actually, the insolation values presented here are not measured but derived values. Complete radiation statistics are available for only a few locations across the U.S. These have been used to interpolate and infer radiation values at adjacent stations based on the meteorology of the area in question and these, in turn, used to estimate other radiation values, such as direct normal radiation. Other numbers given are theoretical in principle but again are based on local meteorological parameters. Some details of these derivation methods are given in the text. Because of their derived nature, the numbers given in the tables and graphs are not exactly correct but in most cases, the errors are within ±5-10% on an annual basis and ±10-15 % on a monthly basis. Seasonal and diurnal patterns in the data do show closely how these quantities actually vary.

Due to inconsistencies in energy units used by science and industry, an appendix of energy conversions has been included.

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1. SOLAR DATA

In order to adequately access how solar radiation values vary over a particular region, basic meteorological parameters which most directly affect the availability of the radiation must also be accessed. Representative sites with sufficient meteorological records were selected for this purpose. Table 1.0 lists these cities alphabetically by site codes and Figure 1.0 displays their locations on the S.E. region map representation.

Figures 1.1-1.28 represent contour analysis of climatological data collected from the NWS (Local Climatological Data) publications for 31 S.E. region stations for the 10 year period 1967-1976 inclusive. The plots themselves were drawn by a Versatec Plotter using a plotting routine generated from the processed raw data by a General Purpose Contouring Program (GPCP) in the computing library here at Tech, performed on Tech's CDC Cyber 74 computer.

These plots are for percent sunshine, sky cover in percent, heating degree days, and cooling degree days for seasonal and annual values. All of these data are of two types: norms and standard deviations from the 10 year mean.

Using thirty year norms of monthly values, the seasonal norms are the average of the norms for the three seasonal months for each season: Dec., Jan., and Feb. for winter; Mar., Apr., and May for spring; June, July, and Aug. for summer; and Sept., Oct., and Nov. for fall. Annual norms were derived by averaging all twelve monthly norms.

The data for percent sunshine and sky cover are shown for all seasons and annual basis while the data for heating and cooling degree days are shown for only winter and annual (heating) and summer and annual (cooling) as these are of primary significance to the consumer.

Percent sunshine is defined as the time the sun was visible relative to the total time the sun was above the horizon for a given day, expressed as a percent. Sunshine durations are often measured using a Campbell-Stokes Sunshine recorder which focuses the solar beam onto a ruled paper chart, leaving a burn mark when the direct beam is observed. The Foster sunshine switch is used at NWS sites. This device electronically integrates the duration of time a shaded photocell reads significantly lower than an unshaded photocell. Hourly sunshine durations can be read off the Campbell-Stokes charts or accumulated from the sunshine switch data and the daily, monthly, etc. percent sunshine durations can be derived from these.

Sky cover values are deduced from ground based observations of apparent cloud cover. These estimations are dependent upon actual cloud cover and cloud base height. The effect is that for the same actual cloud cover (as viewed from space, directly above the observer) a lower base height will give the impression of a greater cloud cover than a higher base level, whereas to the incoming solar radiation both situations will be the same.

Heating and cooling degree days are relative measures of energy requirements for maintaining dwelling temperatures. Based on a temperature of 65°F (18.3°C), the heating and cooling index is found by differencing the ambient mean temperature for a given day and the 65°F reference temperature. Negative differences represent a heating index and positive differences, a cooling index. Thus, for a mean temperature of 45°F, the index would be -20 and 20 heating degree days (Fahrenheit scale; multiply by 5/9 to obtain degree days, reference 18.3°C, in Celsius degree day scale). The heating and cooling degree days are totaled for the month and year. In these graphic representations, the seasonal and annual values plotted are totals for their respective time frames.

Table 1.0. Station Codes, Cities.

AGS	Augusta, GA	JAX	Jacksonville, FL
AQQ	Appalachicola, FL	LAL	Lakeland, FL
ATL	Atlanta, GA	LEX	Lexington, KY
AVL	Ashville, NC	LOU	Louisville, KY
BAL	Baltimore, MD	LYH	Lynchburg, VA
BHM	Birmingham, AL	MCN	Macon, GA
BNA	Nashville, TN	MEI	Meridian, MS
CAE	Columbia, SC	MEM	Memphis, TN
CHA	Chattanooga, TN	MGM	Montgomery, AL
CHS	Charleston, SC	MIA	Miami, FL
CLT	Charlotte, NC	MOB	Mobile, AL
CPT	Cherry Point, NC	MHK	Patuxent River, MD
CRW	Charleston, WV	ORF	Norfolk, VA
DAB	Daytona Beach, FL	ORL	Orlando, FL
DCA	Washington, DC	PBI	West Palm Beach, FL
EYW	Key West, FL	PKB	Parkersburg, WV
GSO	Greensboro, NC	ROU	Raleigh-Durham, NC
GSP	Greenville-Spartanburg, SC	RIC	Richmond, VA
HAT	Capte Hatteras, NC	ROA	Roanoke, VA
HTS	Huntington, WV	SAV	Savannah, GA
ILM	Wilmington, NC	TLH	Tallahassee, FL
JAN	Jackson, MS	TPA	Tampa, FL
		TYS	Knoxville, TN

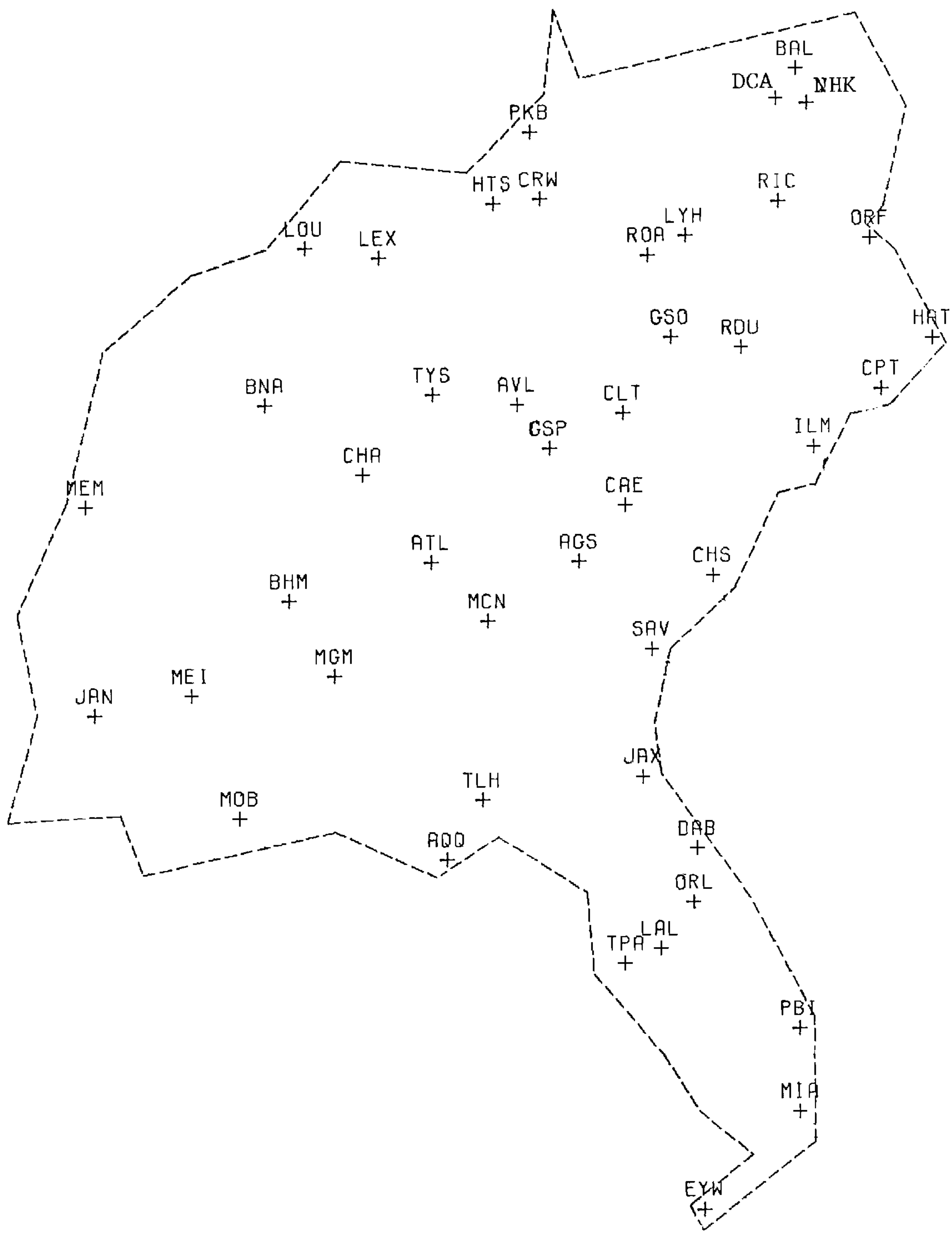

Figure 1.0. Station Locations and Codes.

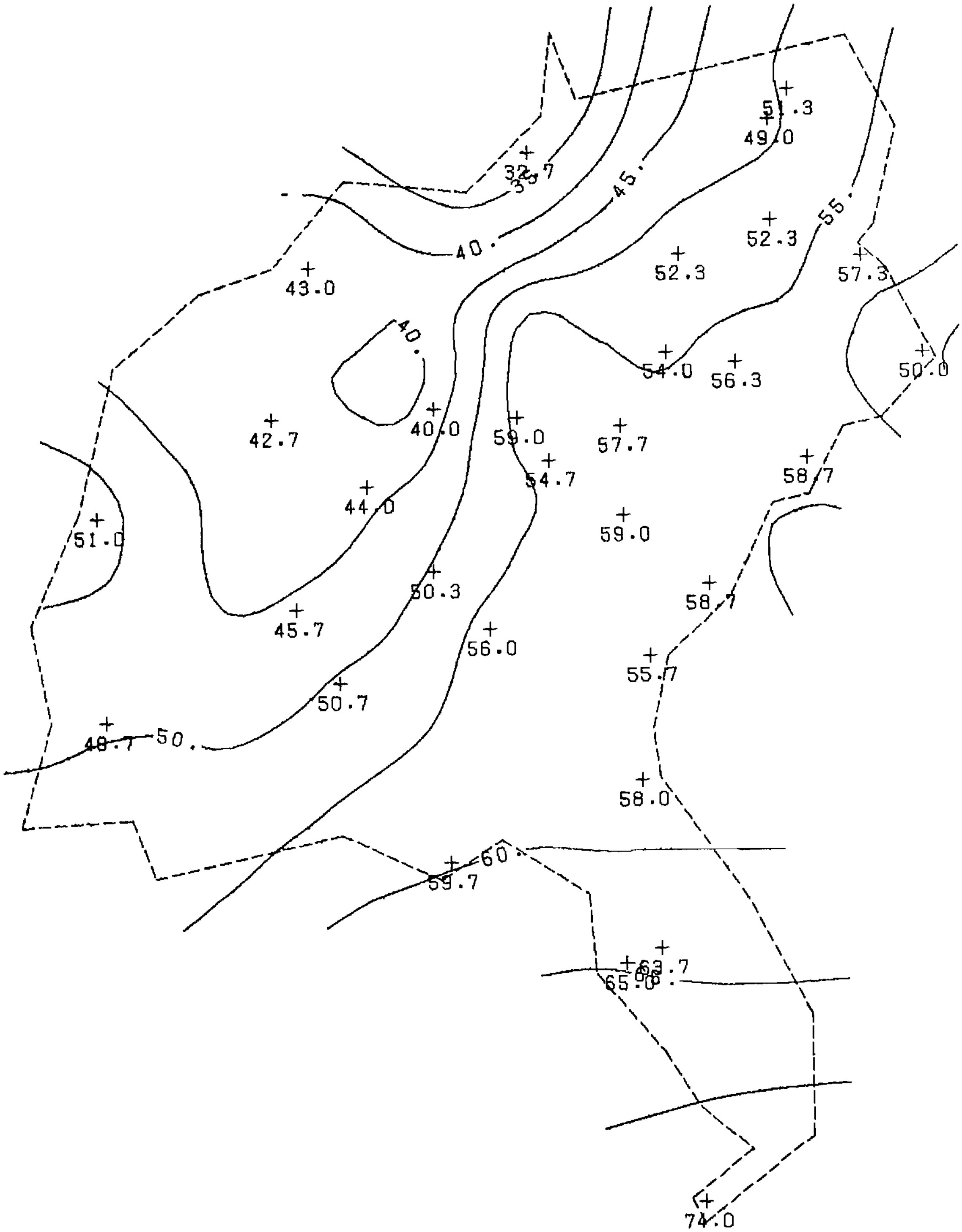

Figure 1.1. Percent Sunshine - Winter Norm.

Figure 1.2. Percent Sunshine - Winter Standard Deviation.

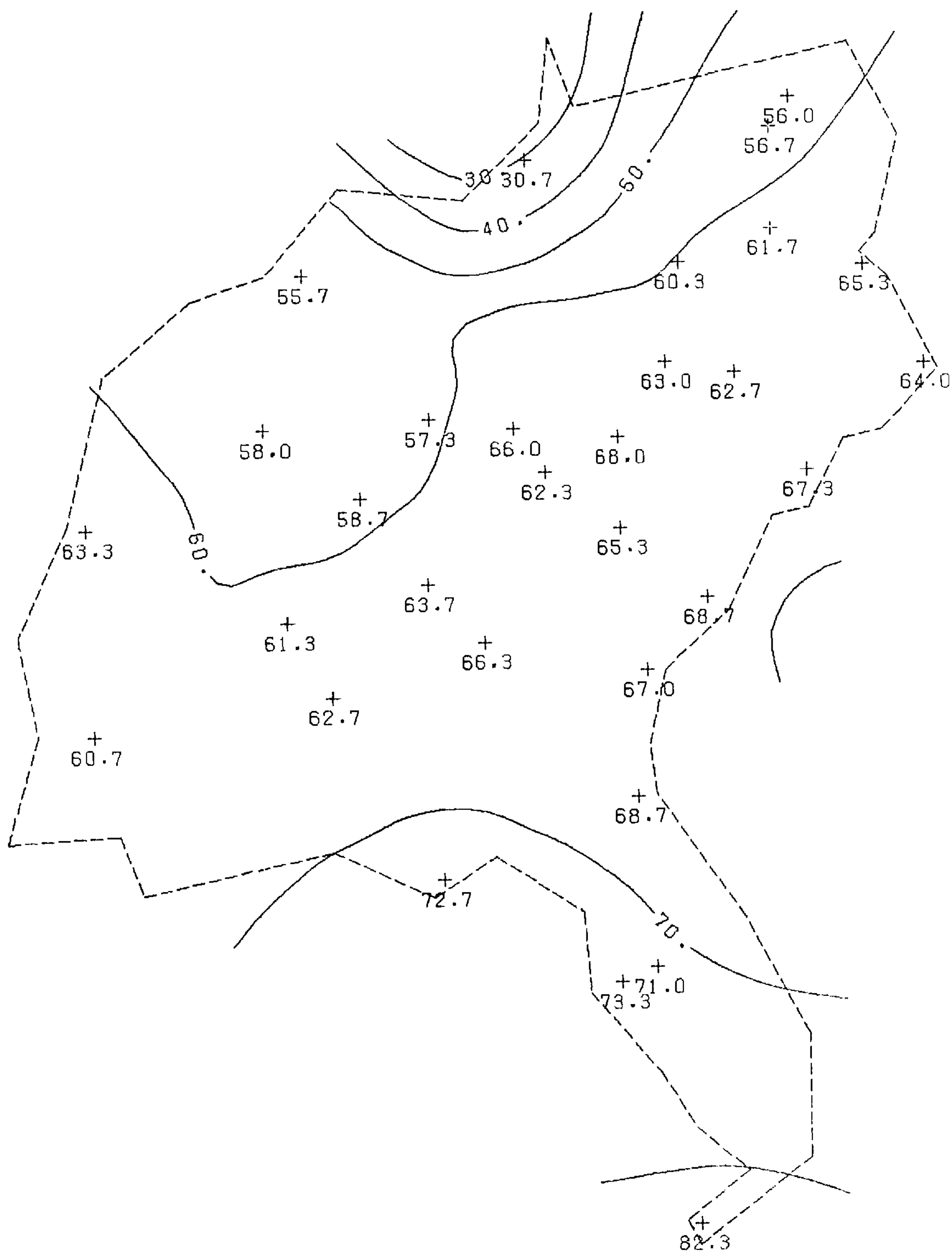

Figure 1.3. Percent Sunshine - Spring Norm.

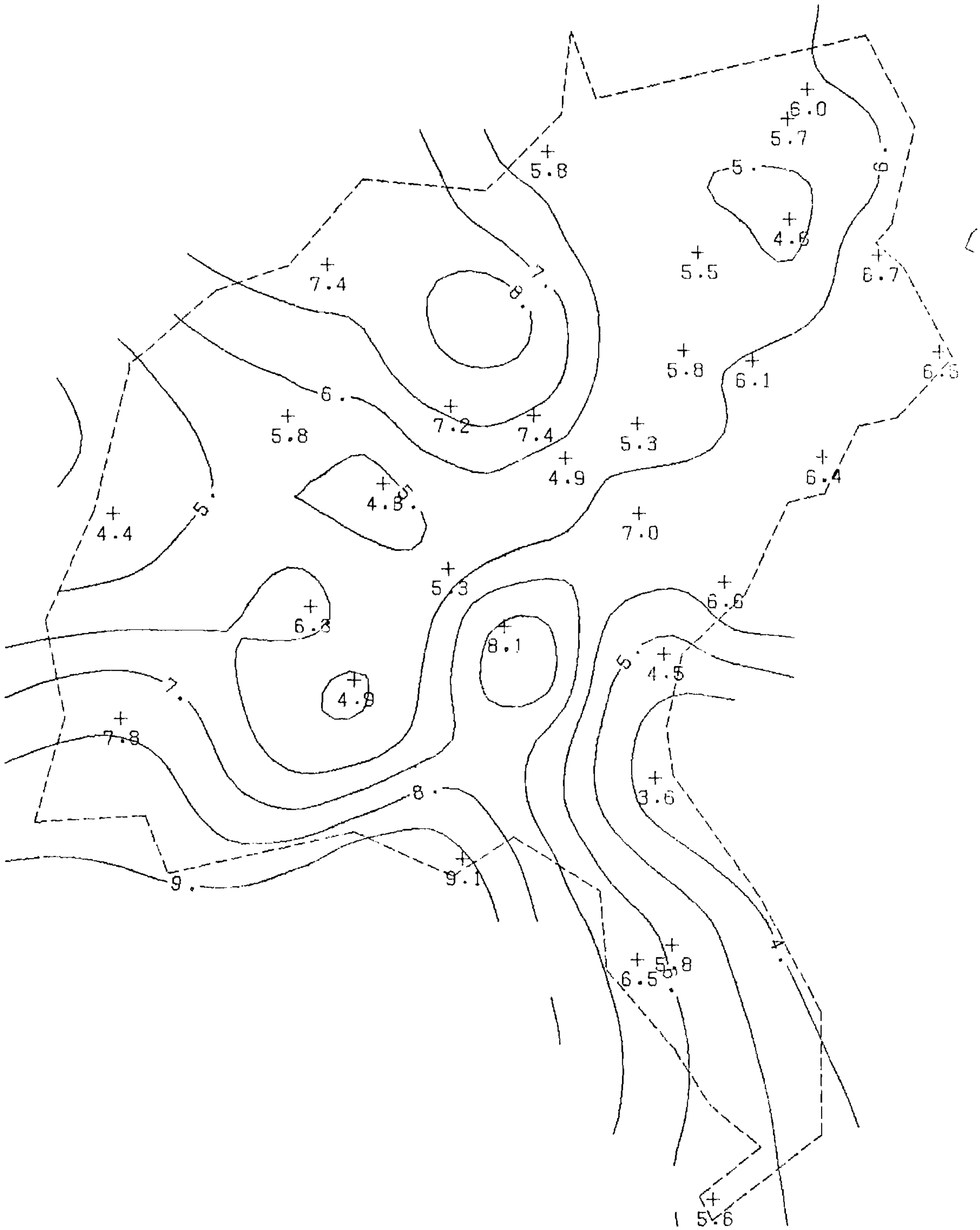

Figure 1.4. Percent Sunshine - Spring Standard Deviation.

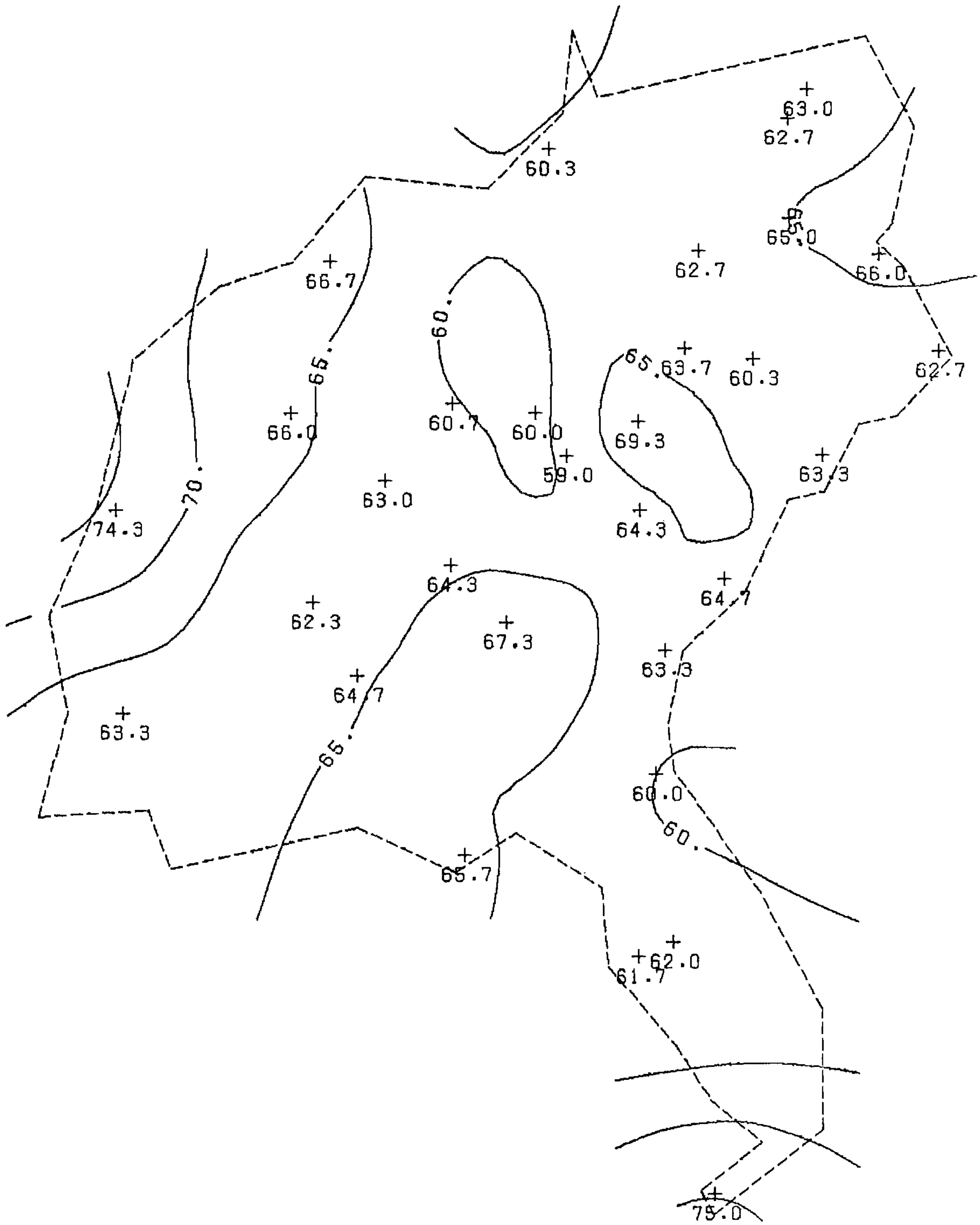

Figure 1.5. Percent Sunshine - Summer Norm.

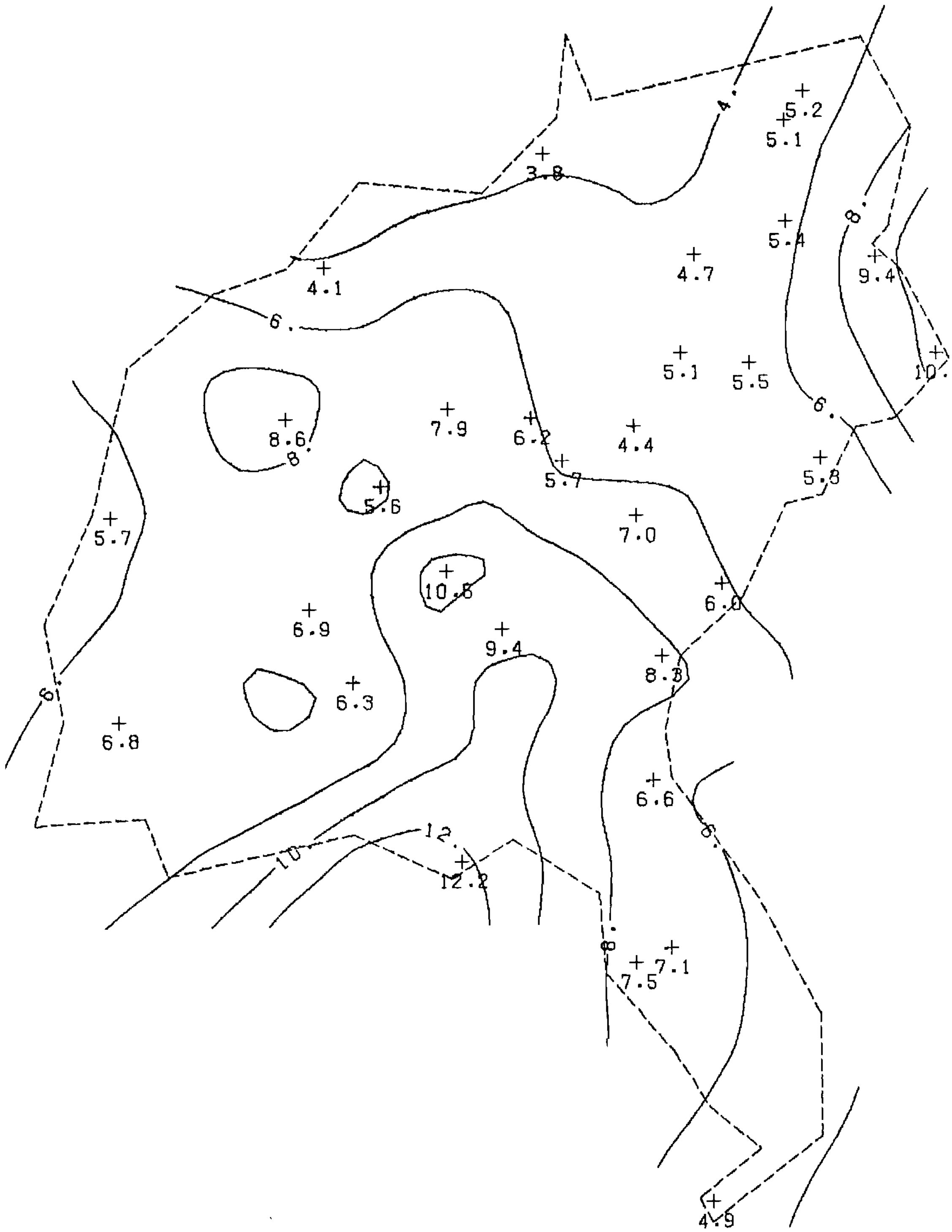

Figure. 1.6. Percent Sunshine - Summer Standard Deviation.

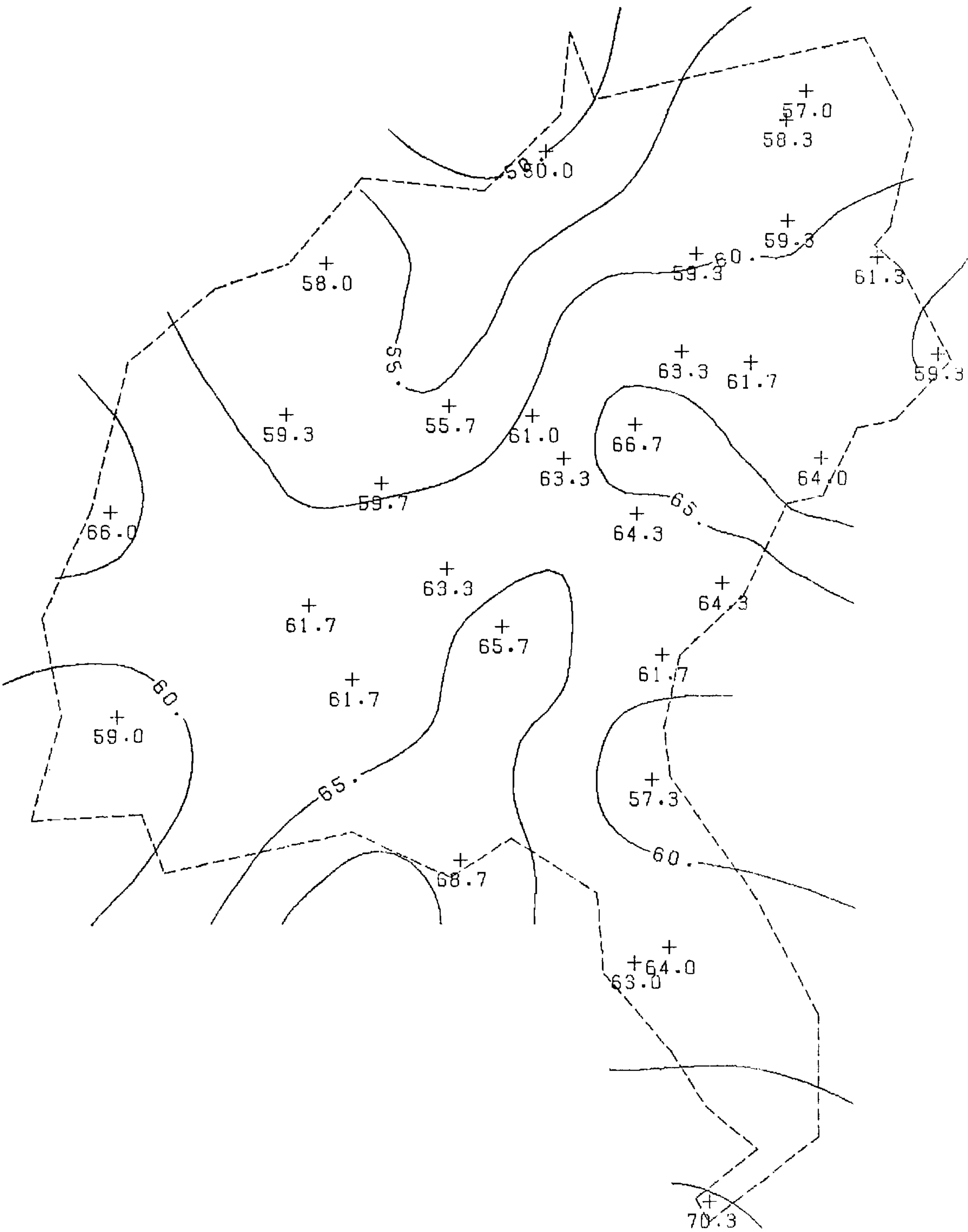

Figure 1.7. Percent Sunshine - Fall Norm.

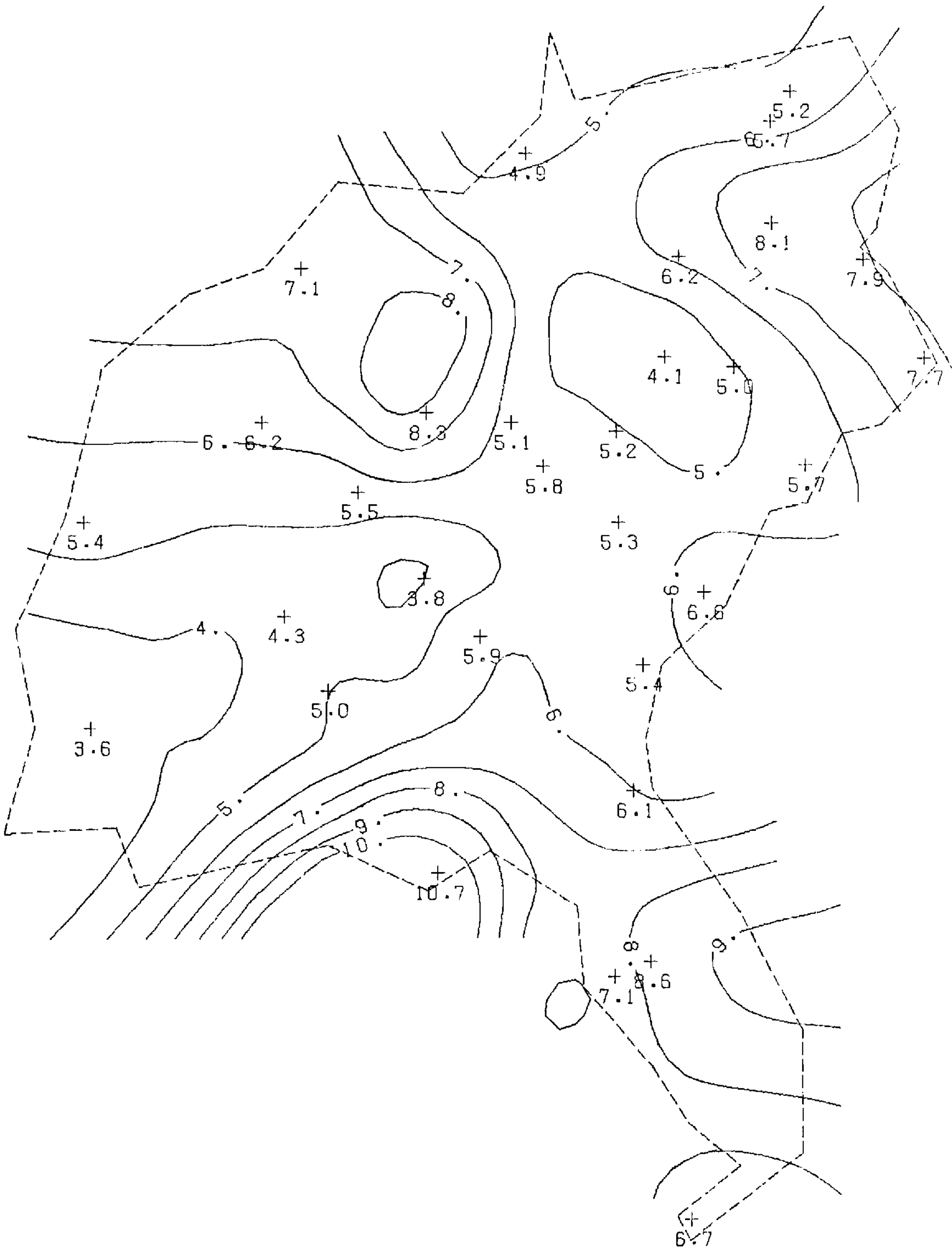

Figure 1.8. Percent Sunshine - Fall Standard Deviation.

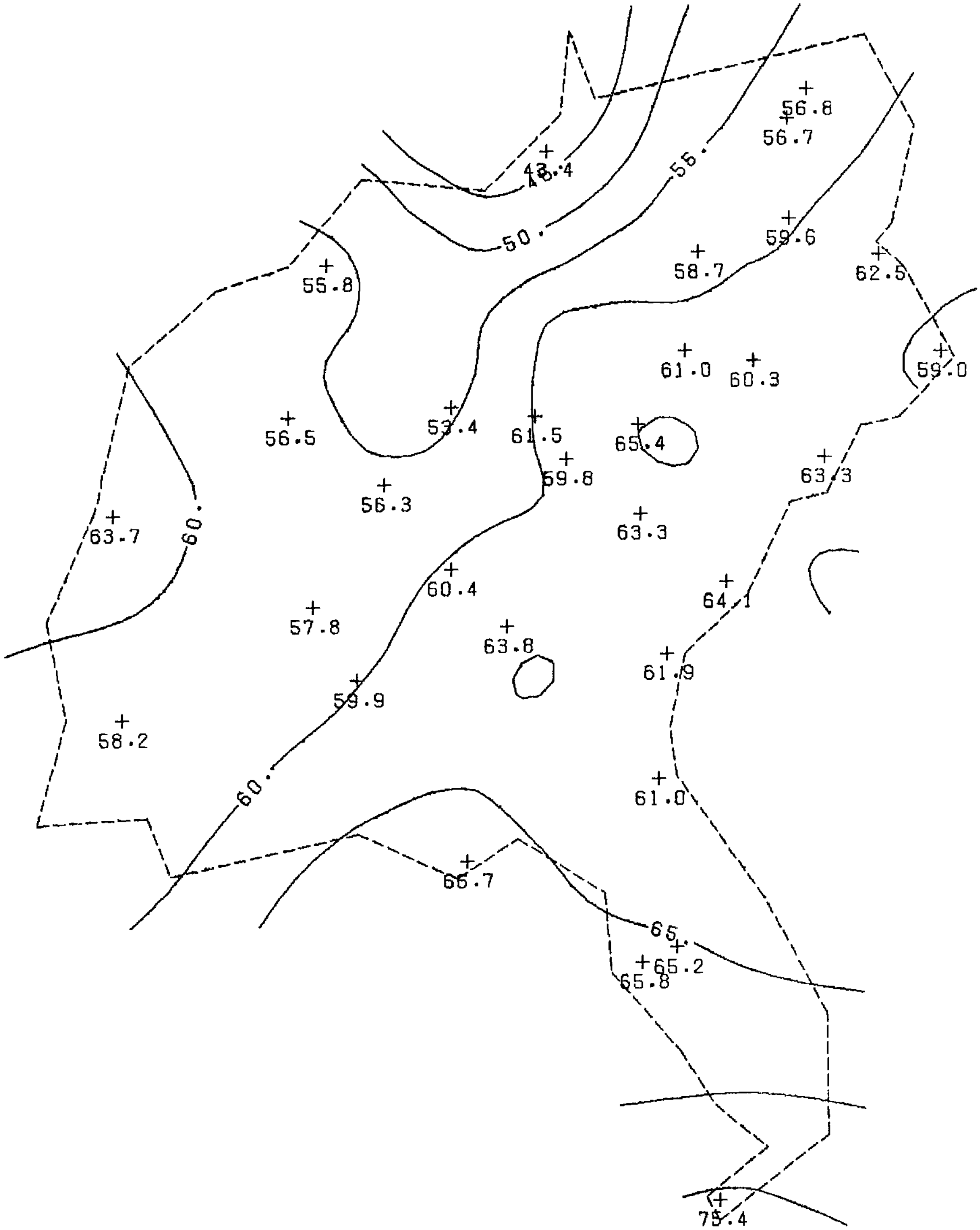

Figure 1.9. Percent Sunshine - Annual Norm.

Figure 1.10. Percent Sunshine - Annual Standard Deviation.

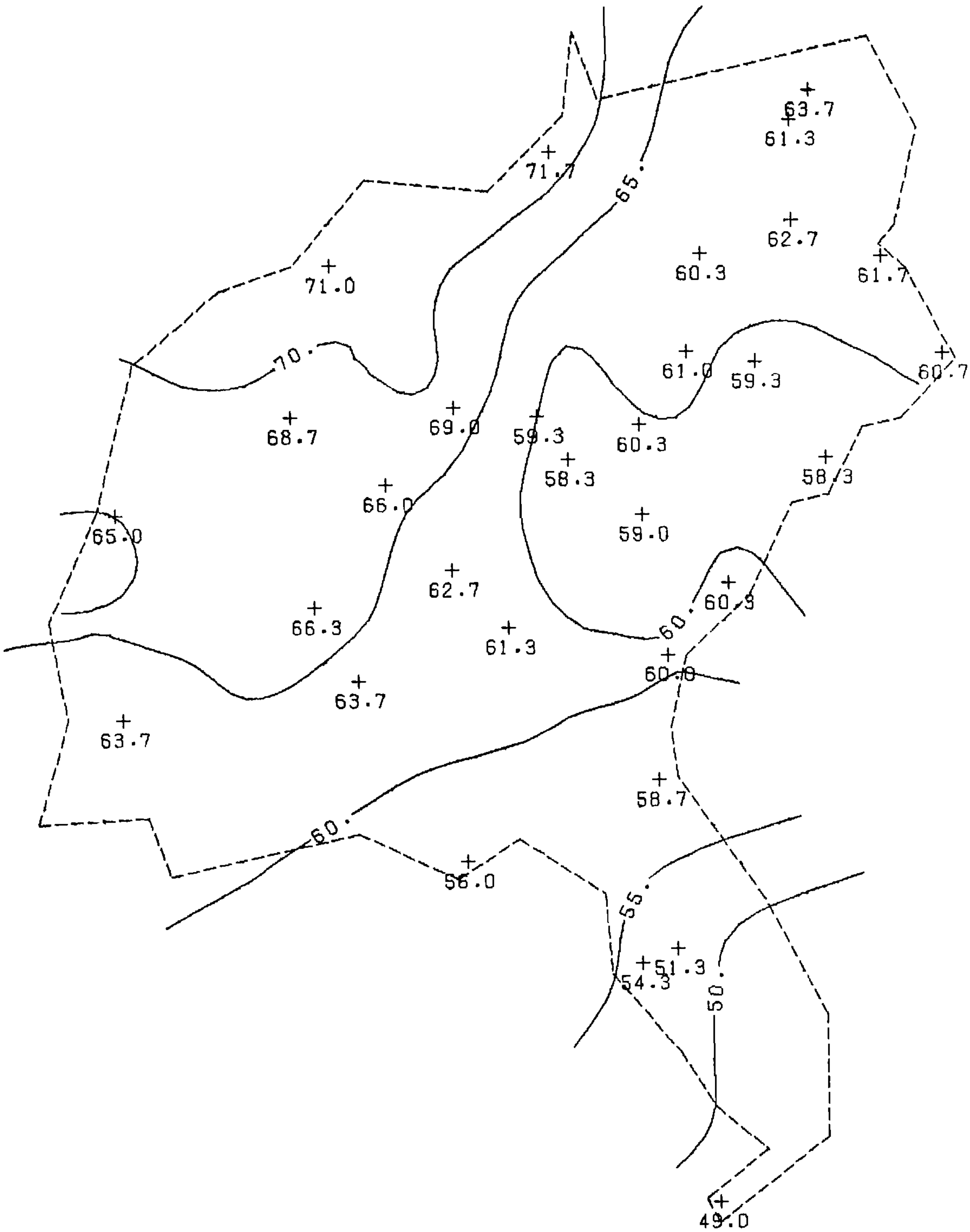

Figure 1.11. Percent Sky Cover - Winter Norm.

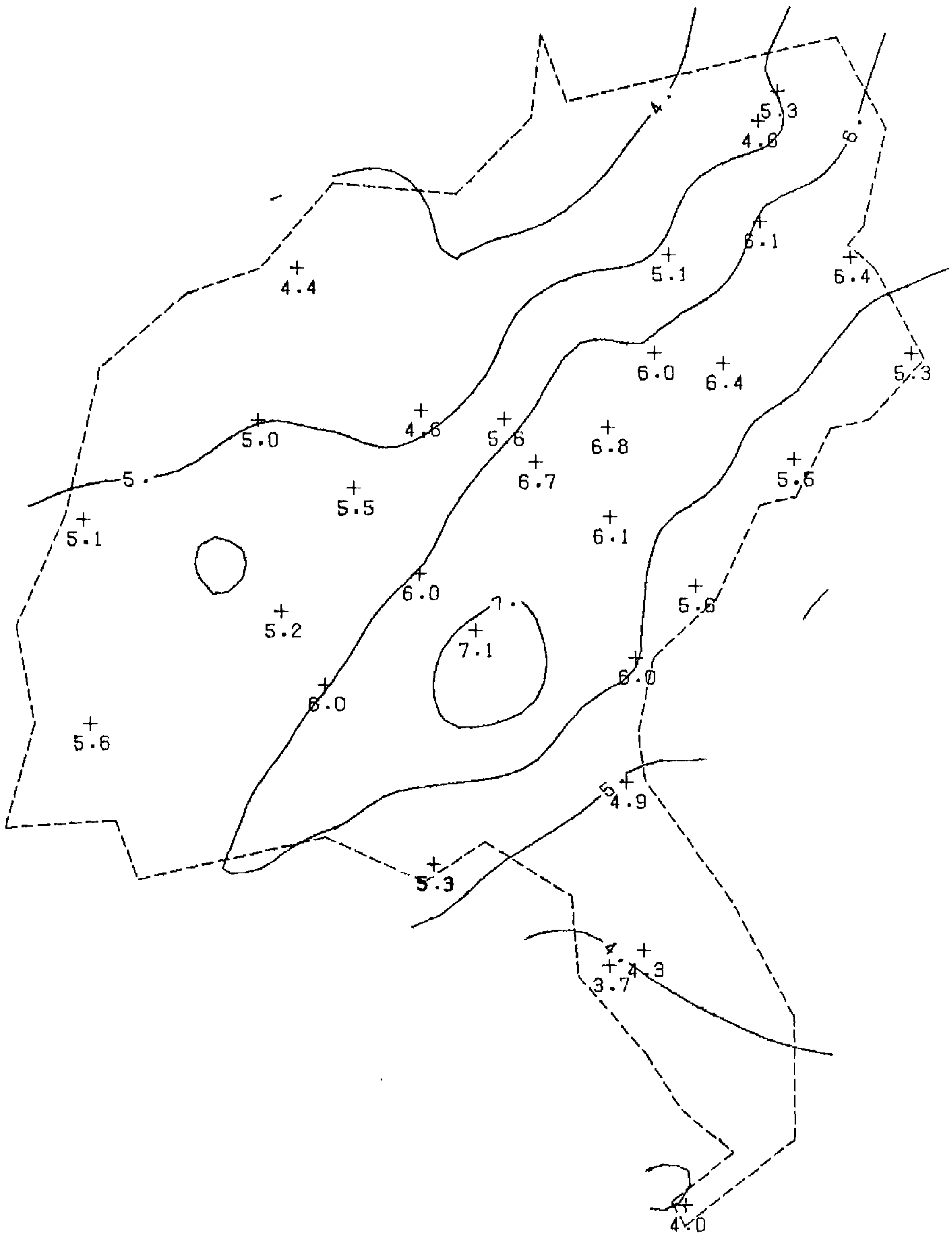

Figure 1.12. Percent Sky Cover - Winter Standard Deviation.

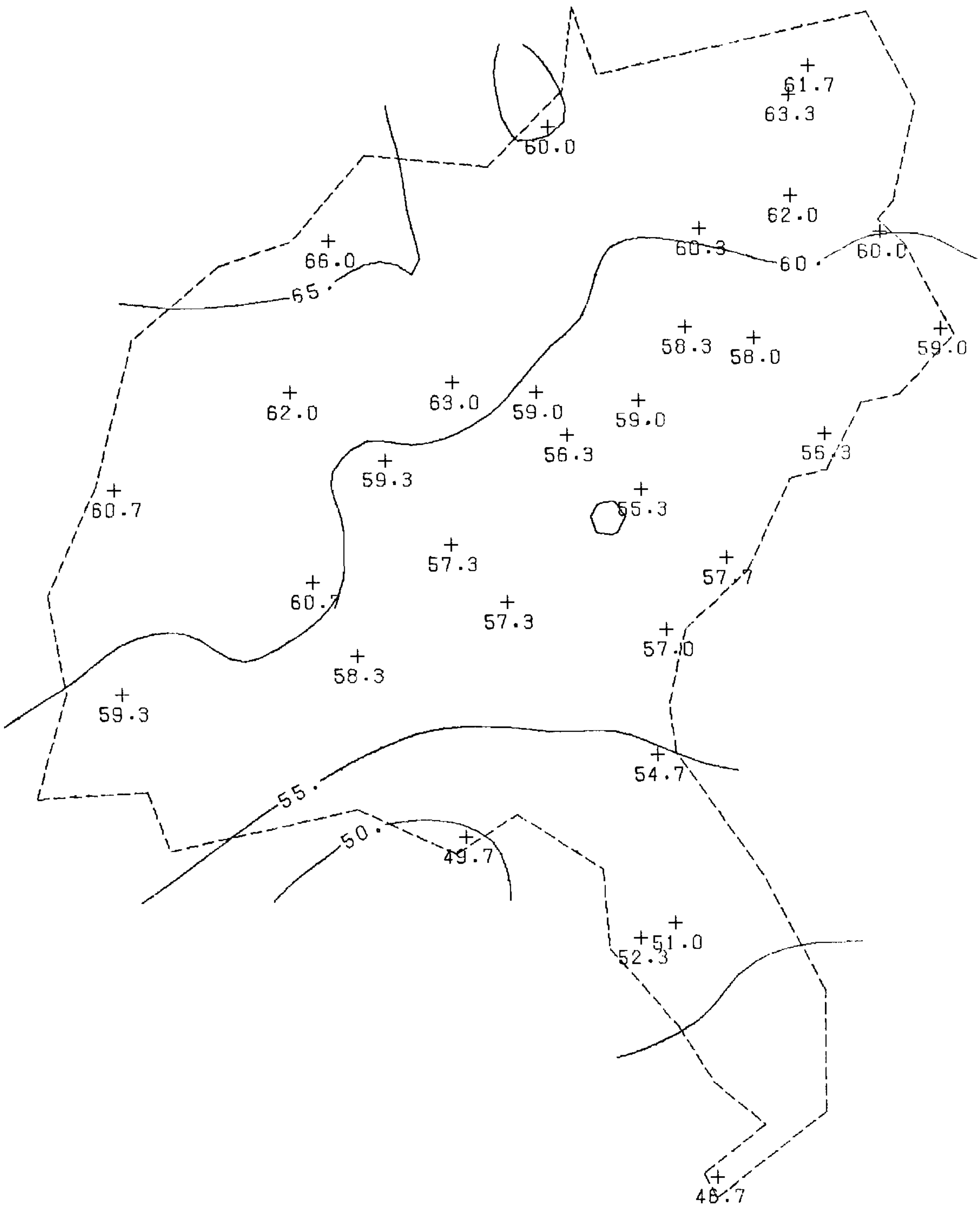

Figure 1.13. Percent Sky Cover - Spring Norm.

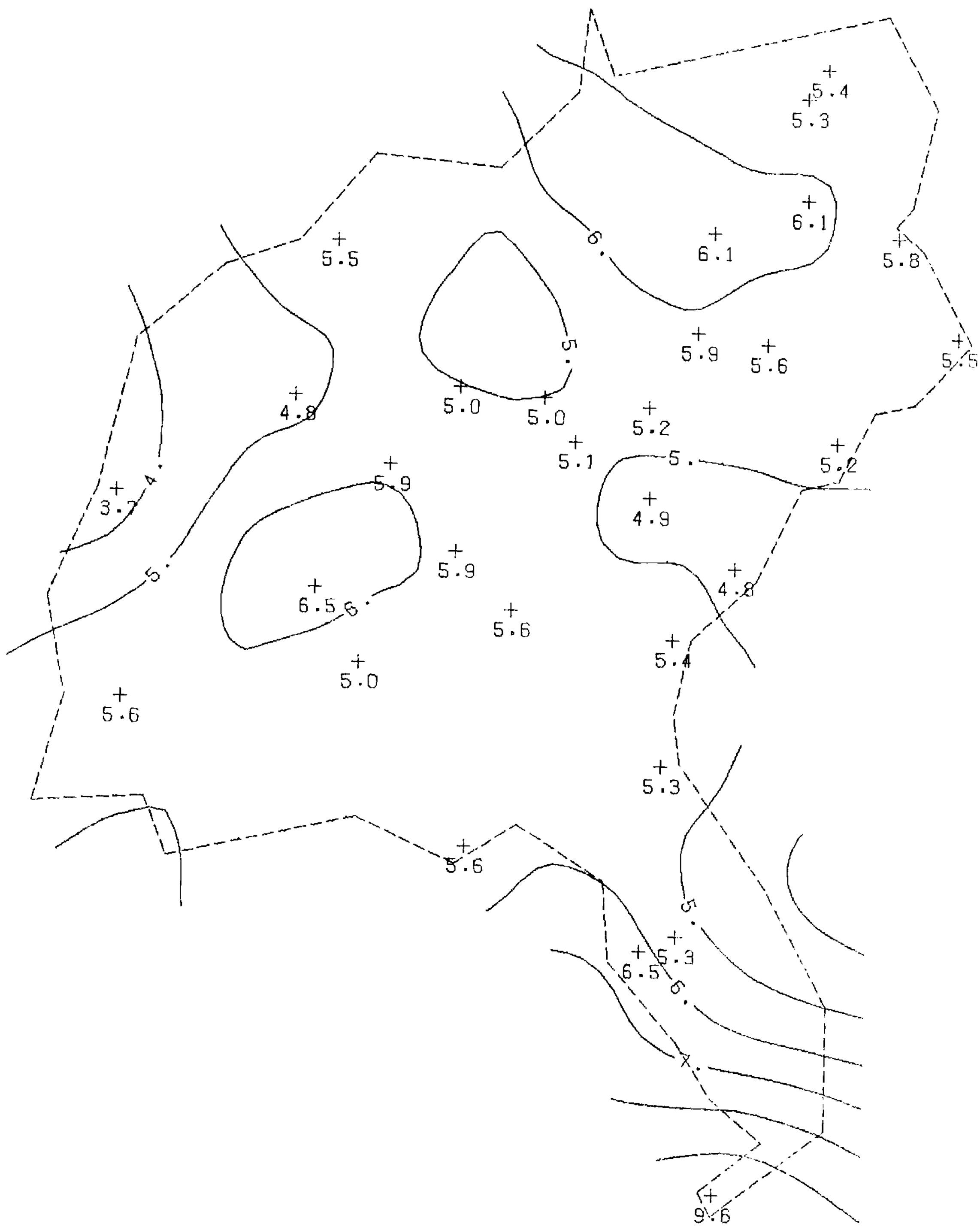

Figure 1.14. Percent Sky Cover - Spring Standard Deviation.

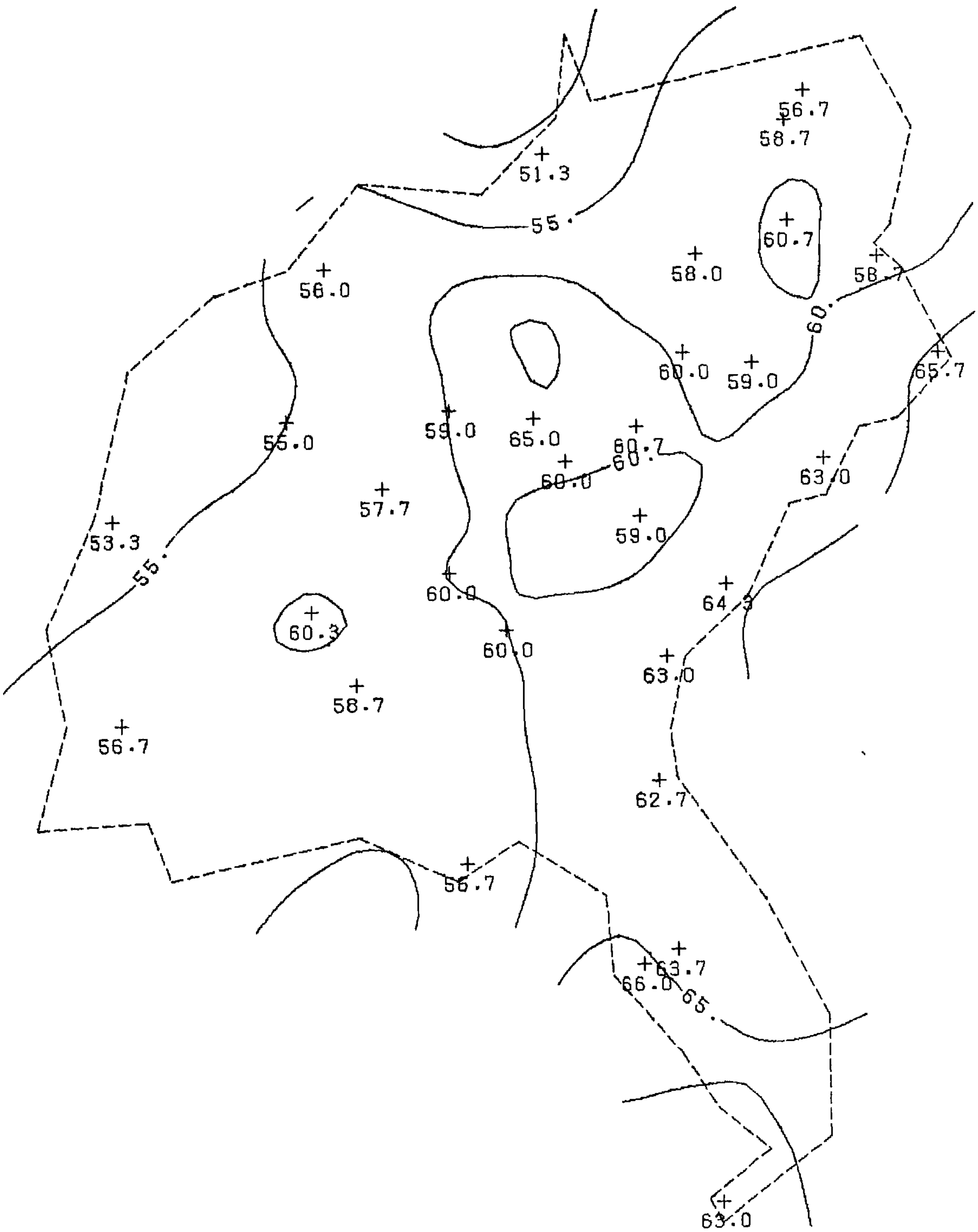

Figure 1.15. Percent Sky Cover - Summer Norm.

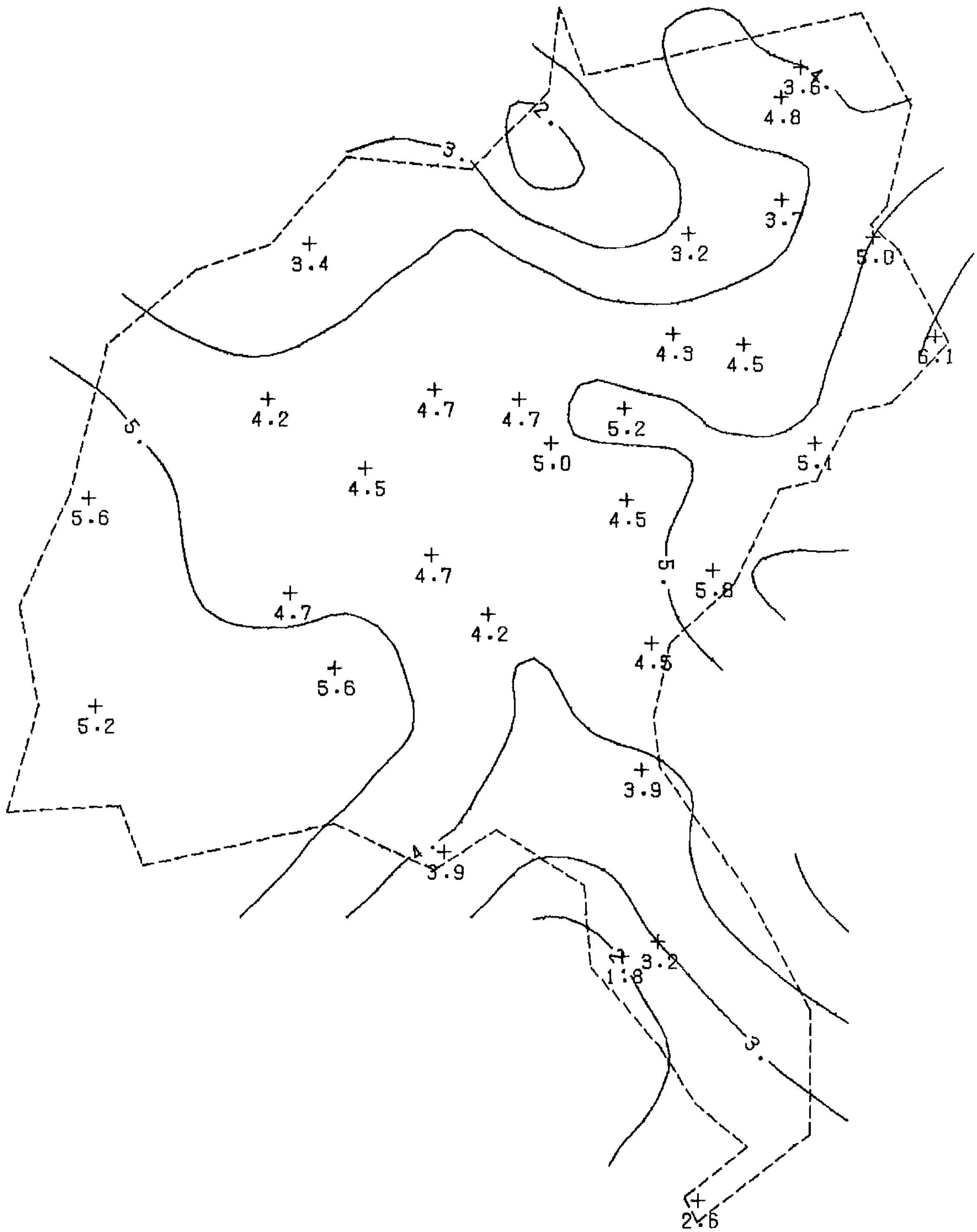

Figure 1.16. Percent Sky Cover - Summer Standard Deviation.

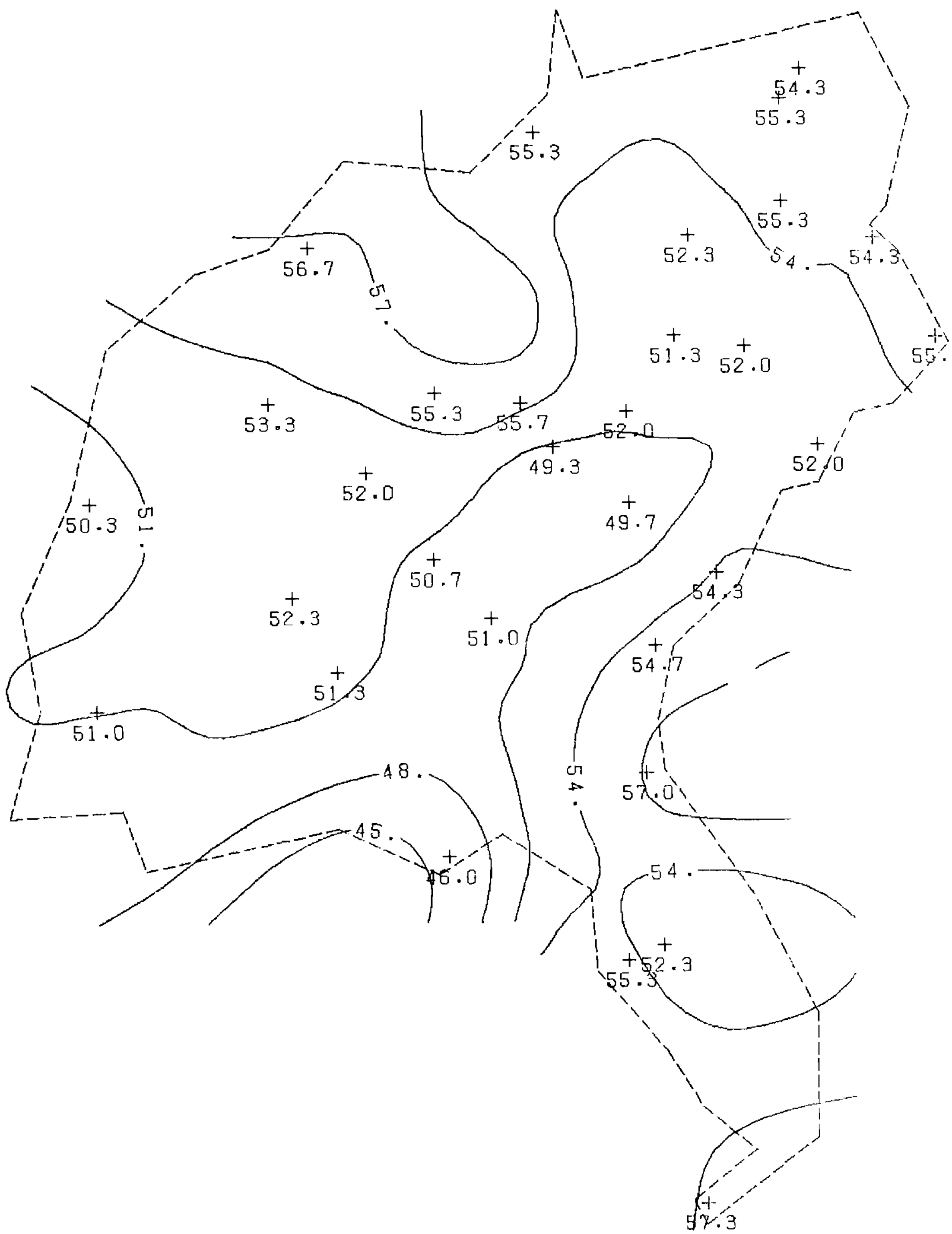

Figure 1.17. Percent Sky Cover - Fall Norm.

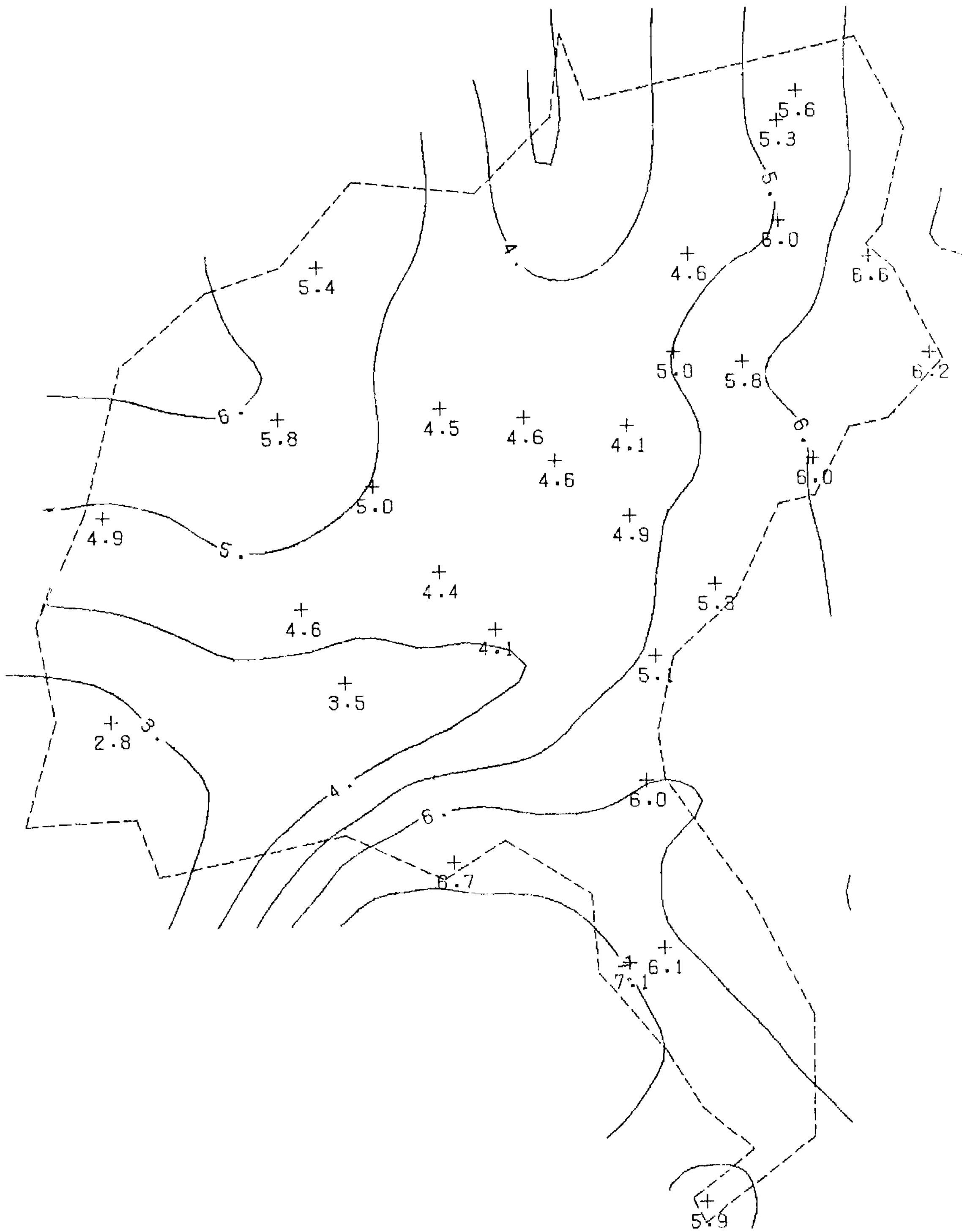

Figure 1.18. Percent Sky Cover - Fall Standard Deviation.

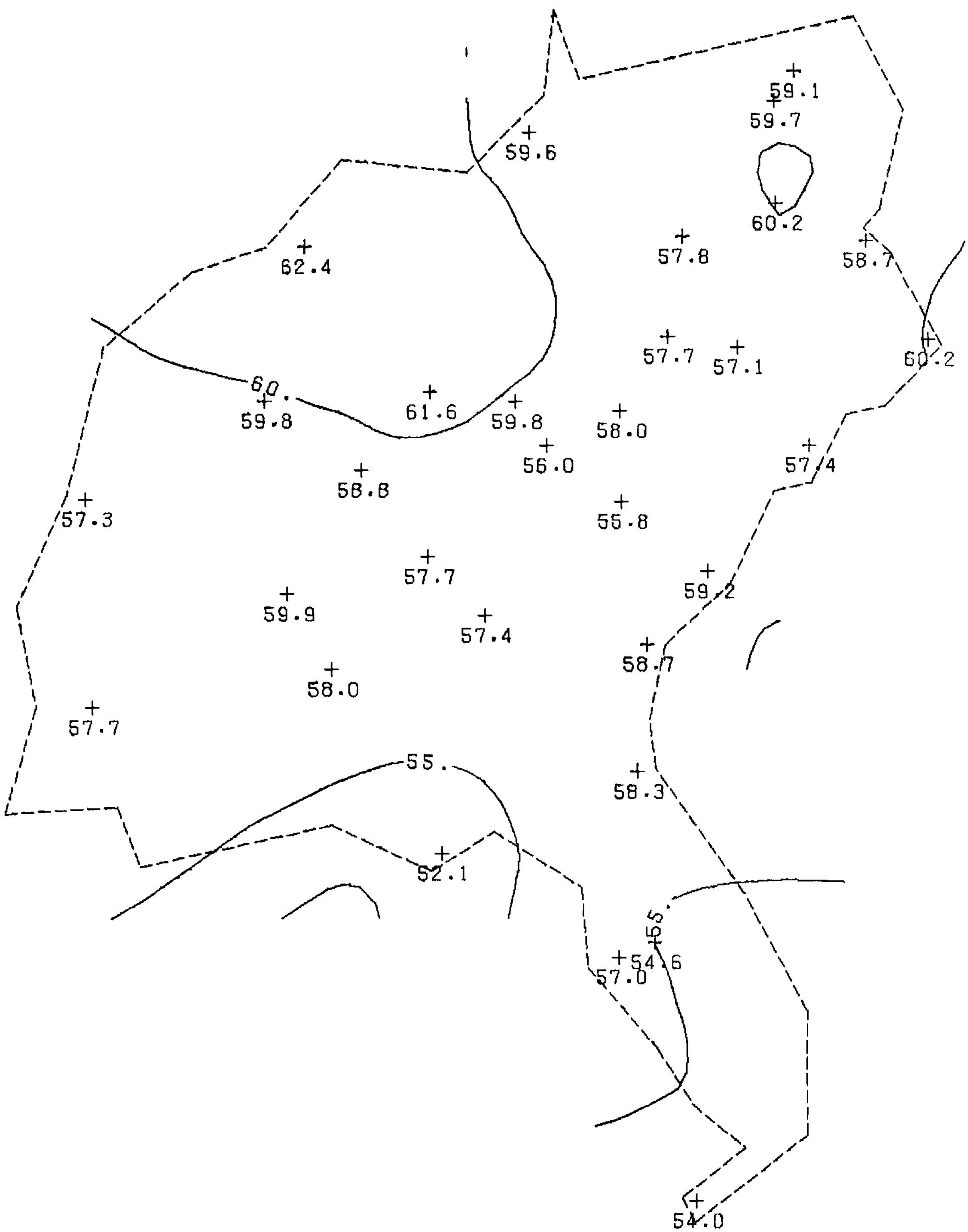

Figure 1.19. Percent Sky Cover - Annual Norm.

Figure 1.20. Percent Sky Cover - Annual Standard Deviation.

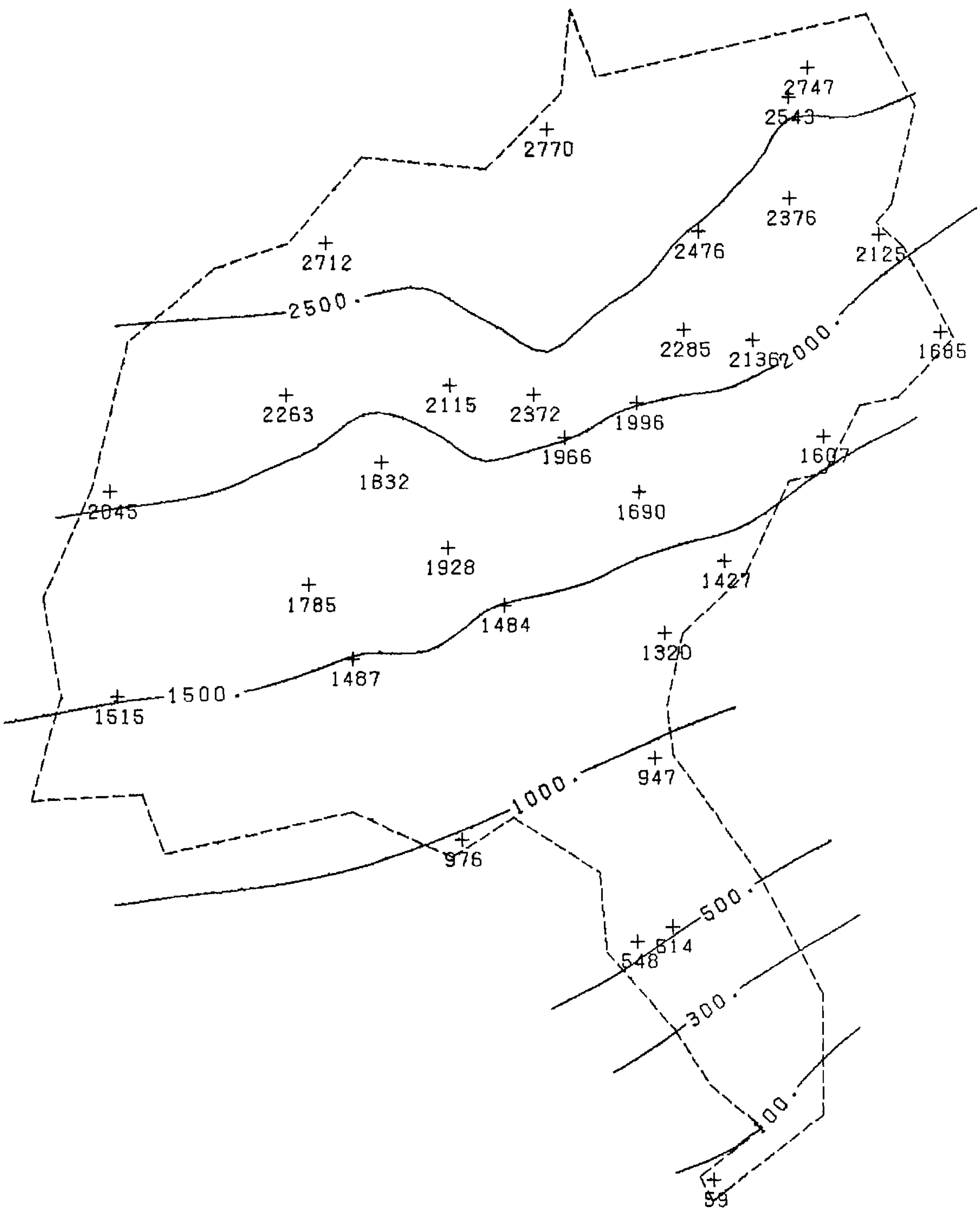

Figure 1.21. Heating Degree Days - Winter Norm.

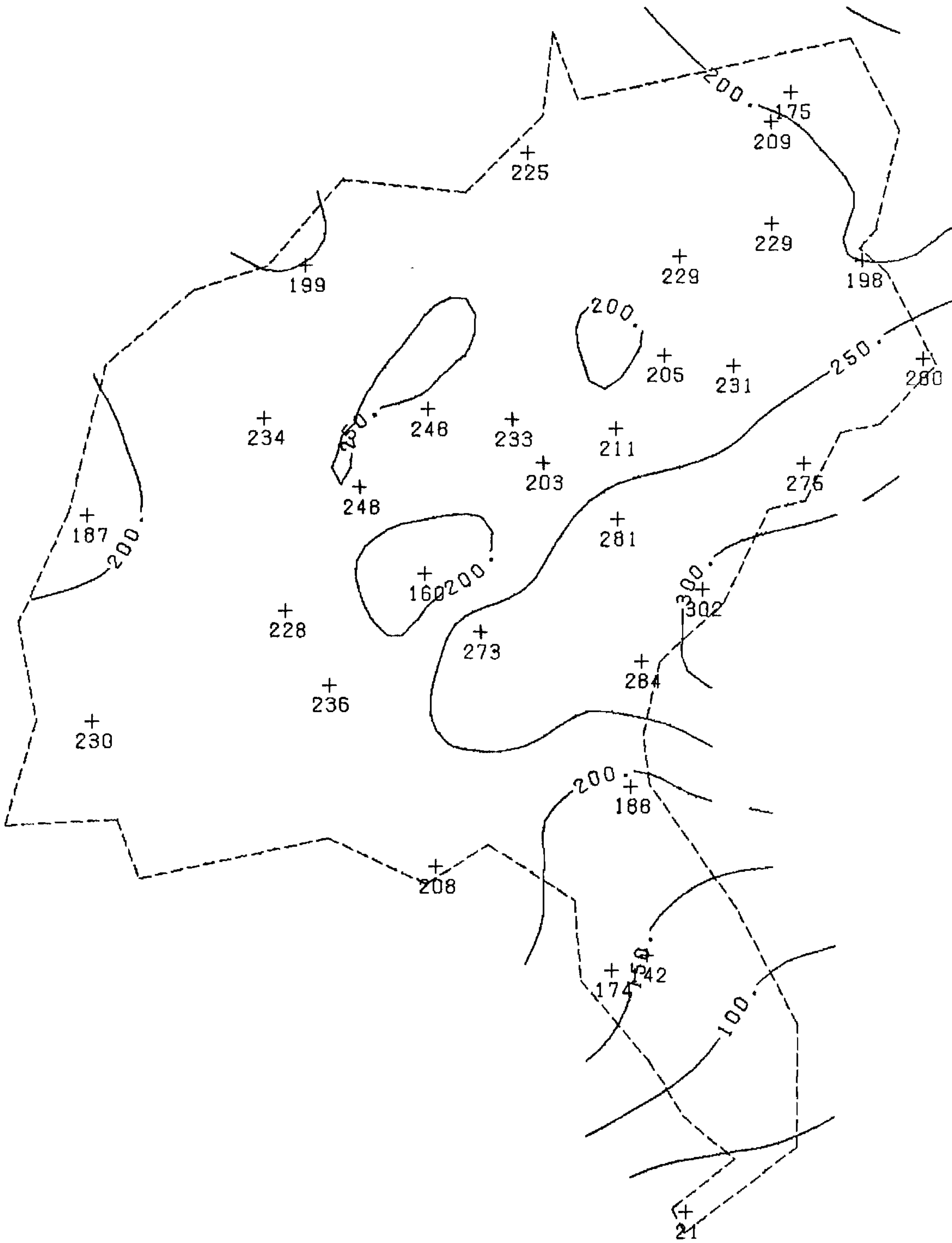

Figure 1.22. Heating Degree Days - Winter Standard Deviation.

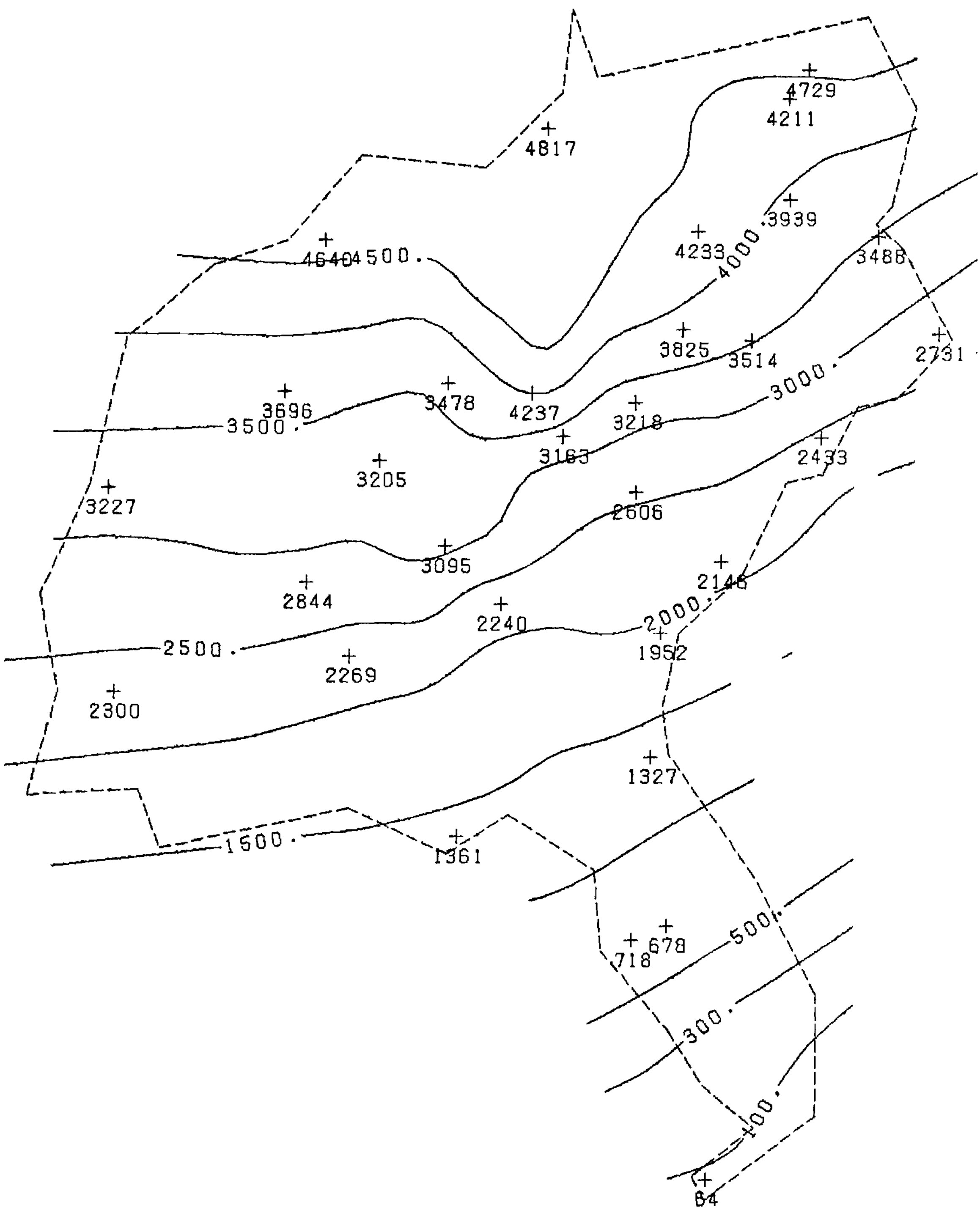

Figure 1.23. Heating Degree Days - Annual Norm.

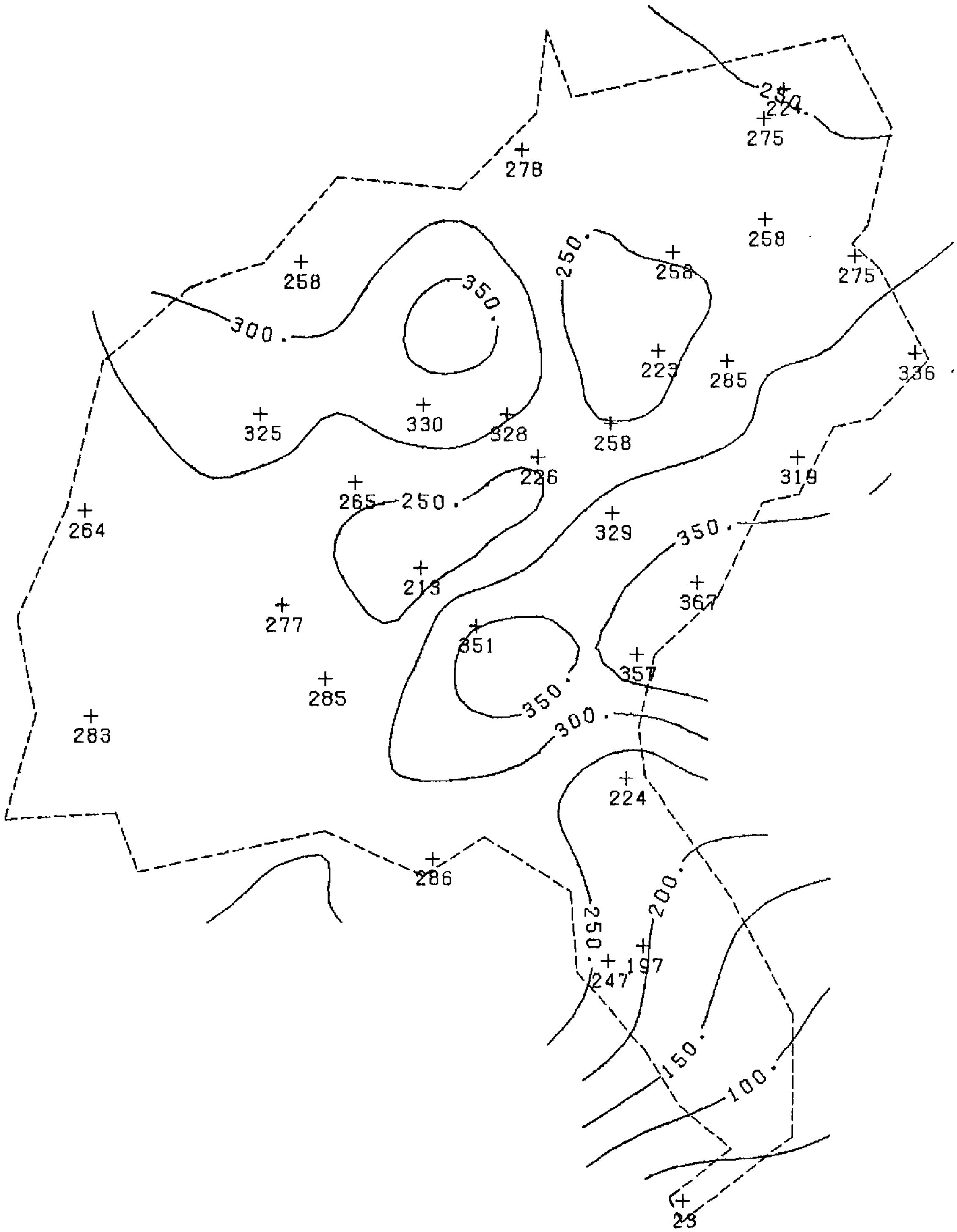

Figure 1.24. Heating Degree Days - Annual Standard Deviation.

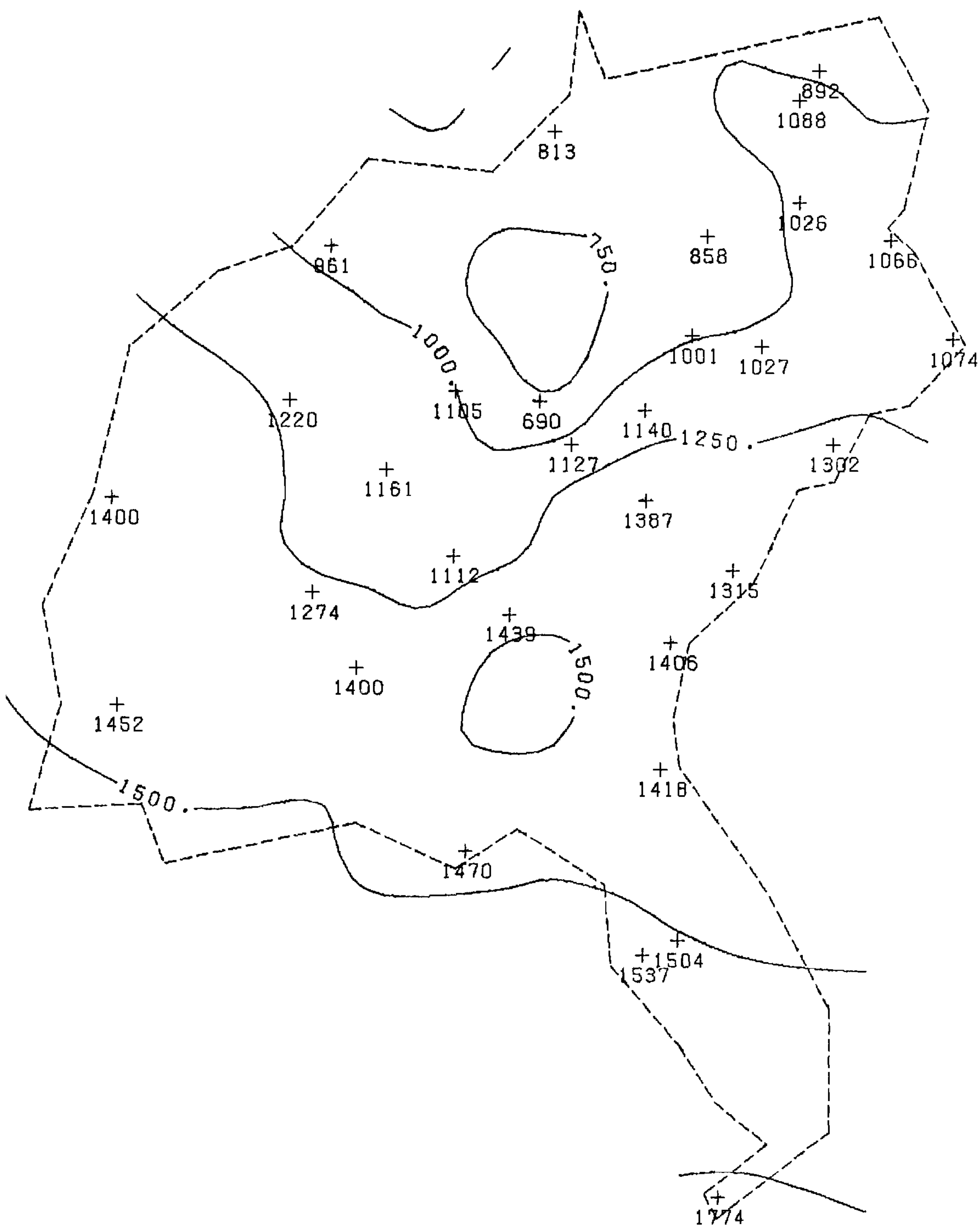

Figure 1.25. Cooling Degree Days - Summer Norm.

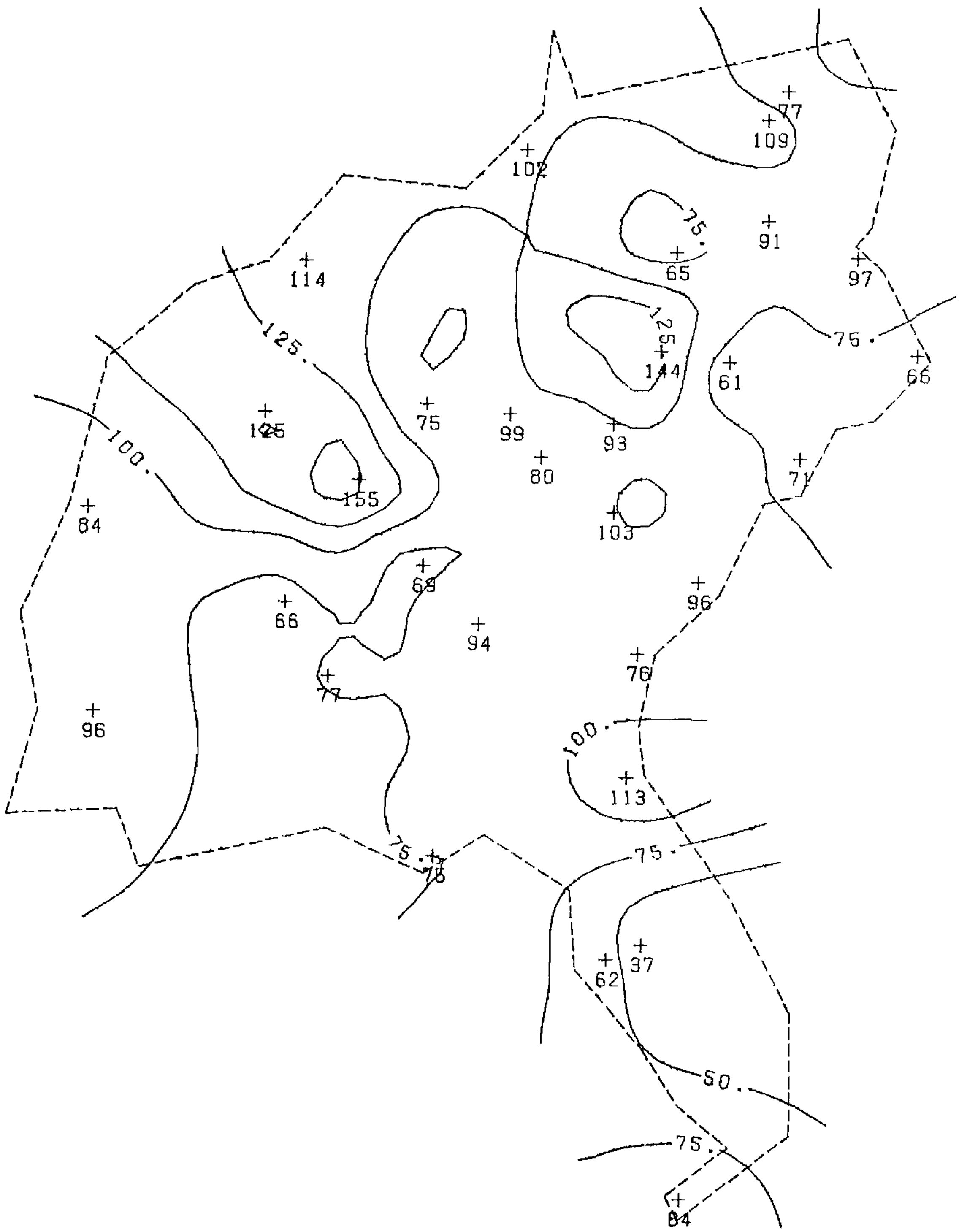

Figure 1.26. Cooling Degree Days - Summer Standard Deviation.

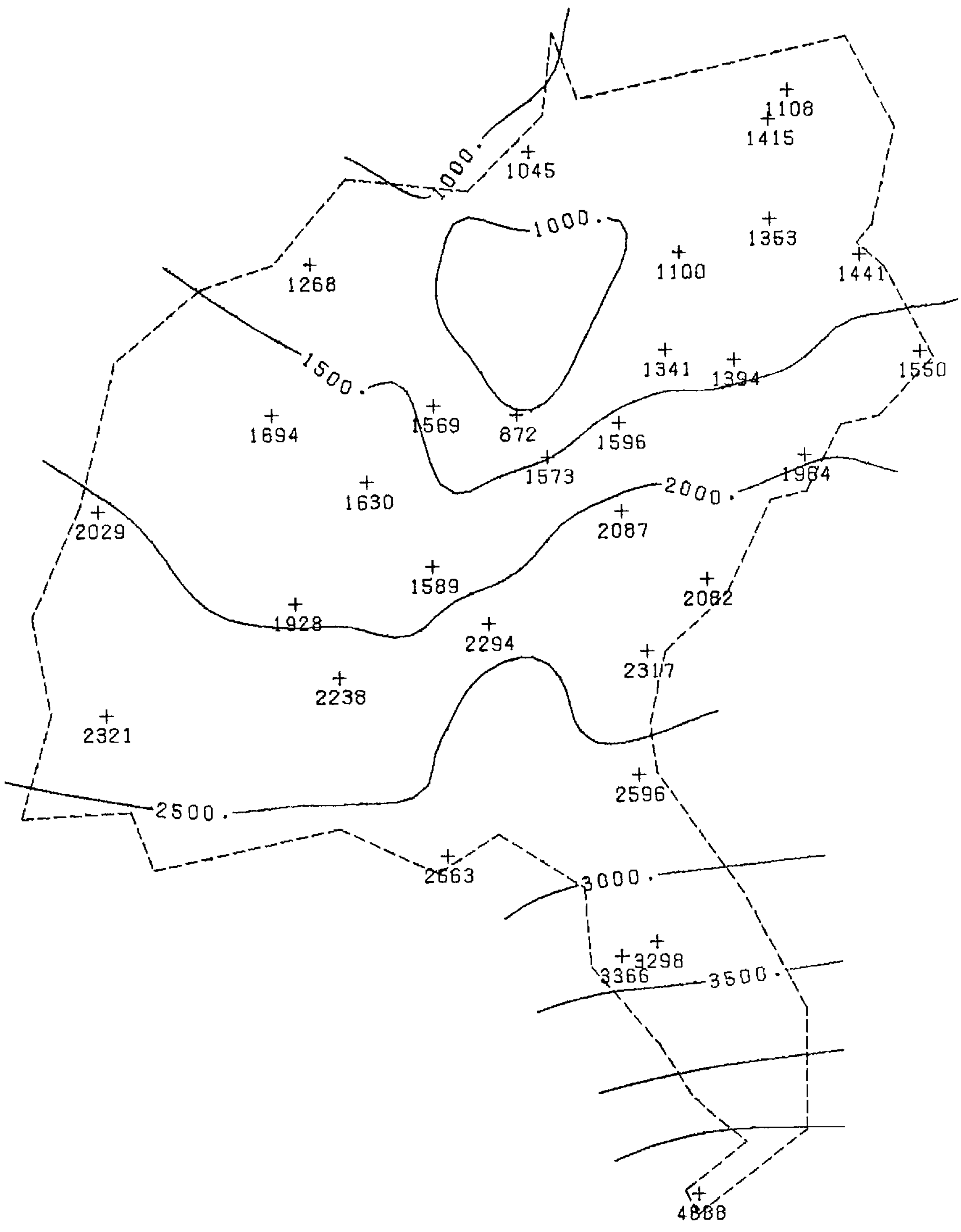

Figure 1.27. Cooling Degree Days - Annual Norm.

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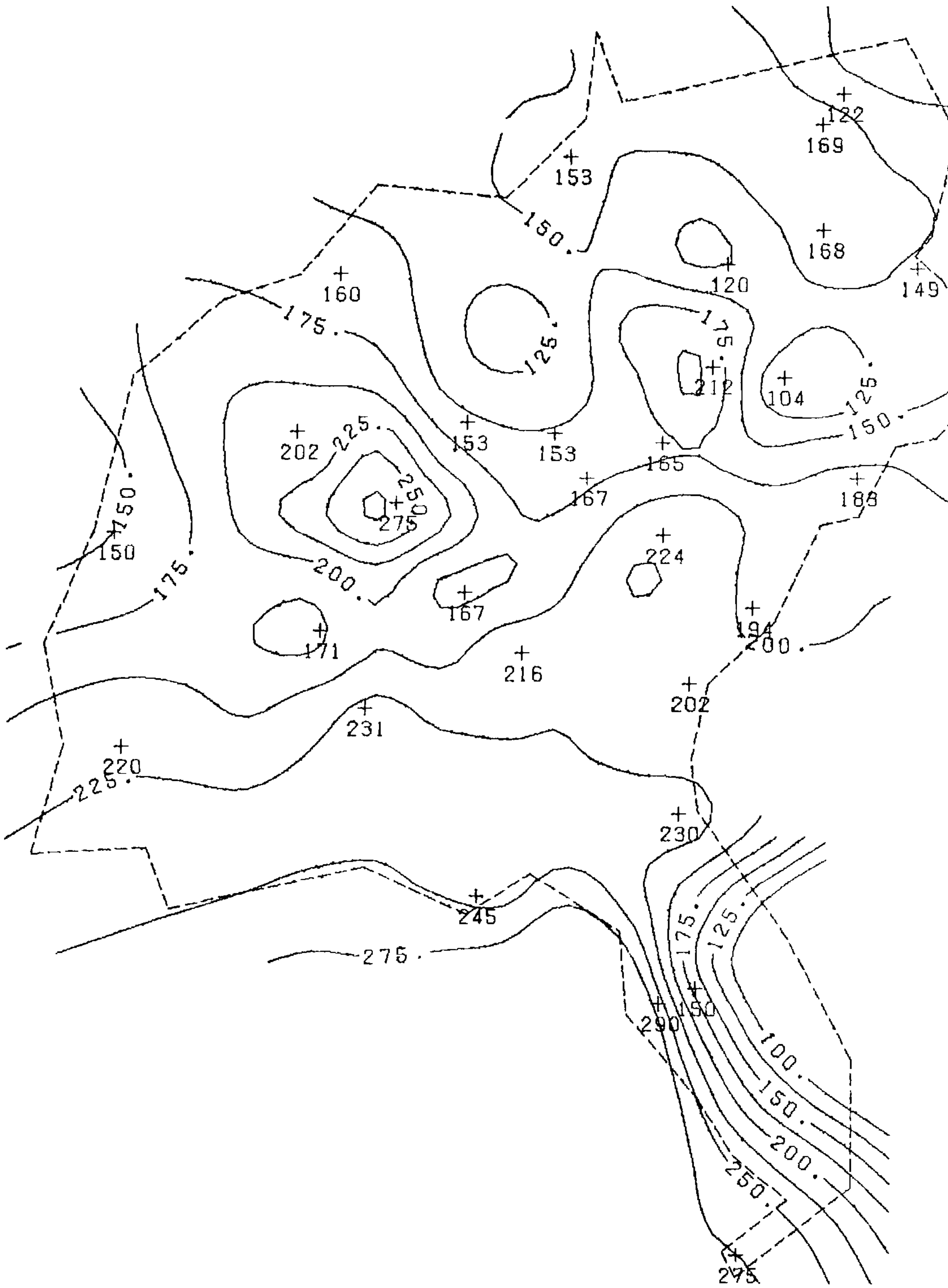

Figure 1.28. Cooling Degree Days - Annual Standard Deviation.

2. TILT PROGRAM DATA

This section presents contour analysis of global horizontal, global at latitude tilt, and direct beam radiation each for seasonal months and annually averaged daily totals. Global horizontal radiation values for stations in the twelve-state southeastern region were taken from Cinquemani, Owenby, and Baldwin (1978). This publication lists monthly and annually averaged daily totals of 248 stations around the U.S. and U.S. territories. The bulk of the data presented were derived from rehabilitated data collected from the 26 Solmet sites. The country was divided into 25 climatologically similar regions, each with a representative Solmet station (New York Central Park was not included as a representative site). The data for each site in a region were derived from linear regression analysis equations developed for the regional Solmet station. These equations were originally intended to be used to fill in gaps in hourly radiation measurements at the station using input of hourly sunshine duration, opaque cloudiness, sky condition, and solar zenith angle. These equations were extended to produce data for the regional stations using their hourly values of these meteorological parameters. The applicability of the regression equations is limited by the restrictions on the solar radiation data used in the rehabilitation process and by the fact that the opaque cloudiness used was very general, that is height, types, and numbers of various layers are not considered.

For the 26 Solmet sites, estimates of the variability in results from the regressions expressed as the ratio of the standard deviation to the mean value range from 10-30% for hourly values, 5-18% for daily values, <7% for monthly values, and from 1-4% for the annual.

Direct normal radiation data is very sparse and incomplete for most of the U.S. as well as the southeastern region under consideration here. These data, plotted and contoured, were derived from global horizontal values by a similar method as that used in the Final Report on Meteorological Data Bases and Improved Direct Insolation Estimates by Randall and Whitson (1977) of the Aerospace Corporation. In their work, hourly direct normal radiation intensities were estimated from hourly global horizontal observations. The formulation used for their estimates used a regression analysis of observed direct normal and global horizontal radiation. By plotting ratios of observed to extraterrestrial hourly direct versus ratios of observed to extraterrestrial hourly global horizontal radiation, a relation was seen and a regression analysis was performed to derive an equation to describe the relation between the two ratios. Using this relation, hourly direct beam radiation can be estimated from hourly global radiation observations.

The errors incurred by this method vary with the time duration of estimation. Individual hourly values showed the greatest error but as these hourly values were compiled over a period of time, the monthly values from the estimated data showed far less error.

For annual estimates of direct radiation for five U.S. stations, errors ranged from -1.89% to +1.46%, the mean error being -0.92% for results using formulations tailored to each station. If the averaged formula factors are used, the errors range from +2.51% to -3.78% and the average error is -0.66%. For monthly estimates of direct radiation for four stations, the errors were significantly larger. For individual stations using averaged factors, the errors ranged from +18.91% to -10.25%. If monthly errors are averaged, the range over the averaged year is from +4.67 to -4.89. It is interesting to note that the largest errors occurred during winter and summer months, negative errors in the winter and positive in the summer. The errors were defined as

$$\% \text{ Error} = \frac{(D_{obs} - D_{est})}{D_{obs}} \times 100\%$$

which indicates the model underestimates direct beam radiation in the summer and overestimates in the winter.

Hourly estimates generally were less variable in their errors from observed values than those for monthly estimates. Although the magnitudes were sometimes greater, the major portion of hourly estimation errors fell within a range of +3.00% but mangitudes as large as 22.7% also occurred.

For the purposes of this study, tabulated values of monthly averaged daily total hemispheric radiation as observed at the 26 Solmet sites and their estimated direct-normal radiation amounts from the Randall-Aerospace Report were used to determine a similar algorithm for estimating monthly averaged daily total direct normal insolation from observed (or in this case, derived) monthly averaged global-horizontal radiation readings for southeastern region sites. A plot of the ratios of estimated monthly averaged daily total direct to the extraterrestrial direct normal versus the ratio of observed monthly averaged daily total hemispheric to extraterrestrial hemispheric radiation for the 26 Solmet sites is shown in Fig. 2.0.

Figures 2.1-2.15 give the contour analysis for global horizontal, global at tilt, and direct beam radiation derived by the method discussed above. Figures 2.11-2.15 show insolation for seasonal months and annually averaged daily totals of global radiation on a latitude-tilted surface. The data contoured here were generated from input of the global horizontal radiation at the 40 southeast region sites utilizing the method of Liu and Jordan (1960) to get radiation values for tilt angles from 0-90° and the latitude angle. It has been found that a latitude tilt is a good compromise between other fixed angles of tilt for a flat-plate collector which might optimize summer or winter available solar energy.

One should keep in mind that these contour representations indicate general climatological values for a region. Interpolation to deduce precise values for a particular location should only be done with this in mind. Local climatology due to orography, urban effects, or other influences must be considered in order to determine how these parameters may vary from actual quantities compared to those interpolated from the maps. Also, the contour analyses, being computer generated, may not always be exact in their positioning relative to a value at the stations. Thus, the contours are only to be used for a rough, general idea of the geographic variation over the region for the parameter being plotted.

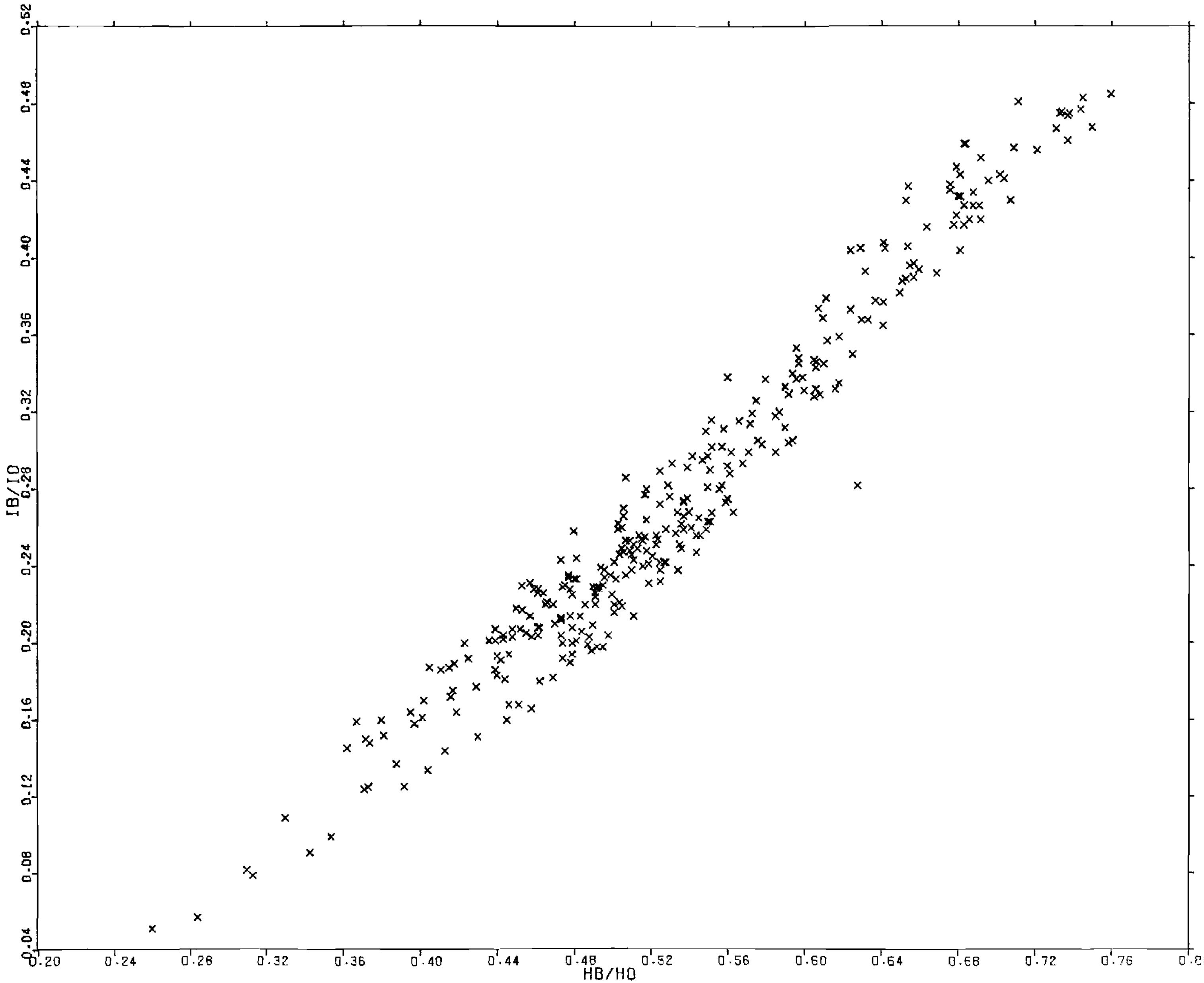

Figure 2.0. Ratios of Monthly Averaged Daily Total Terrestrial to Extraterrestrial Direct Radiation Versus Ratios of Terrestrial to Extraterrestrial Global Horizontal Radiation for the 26 SOLMET Sites.

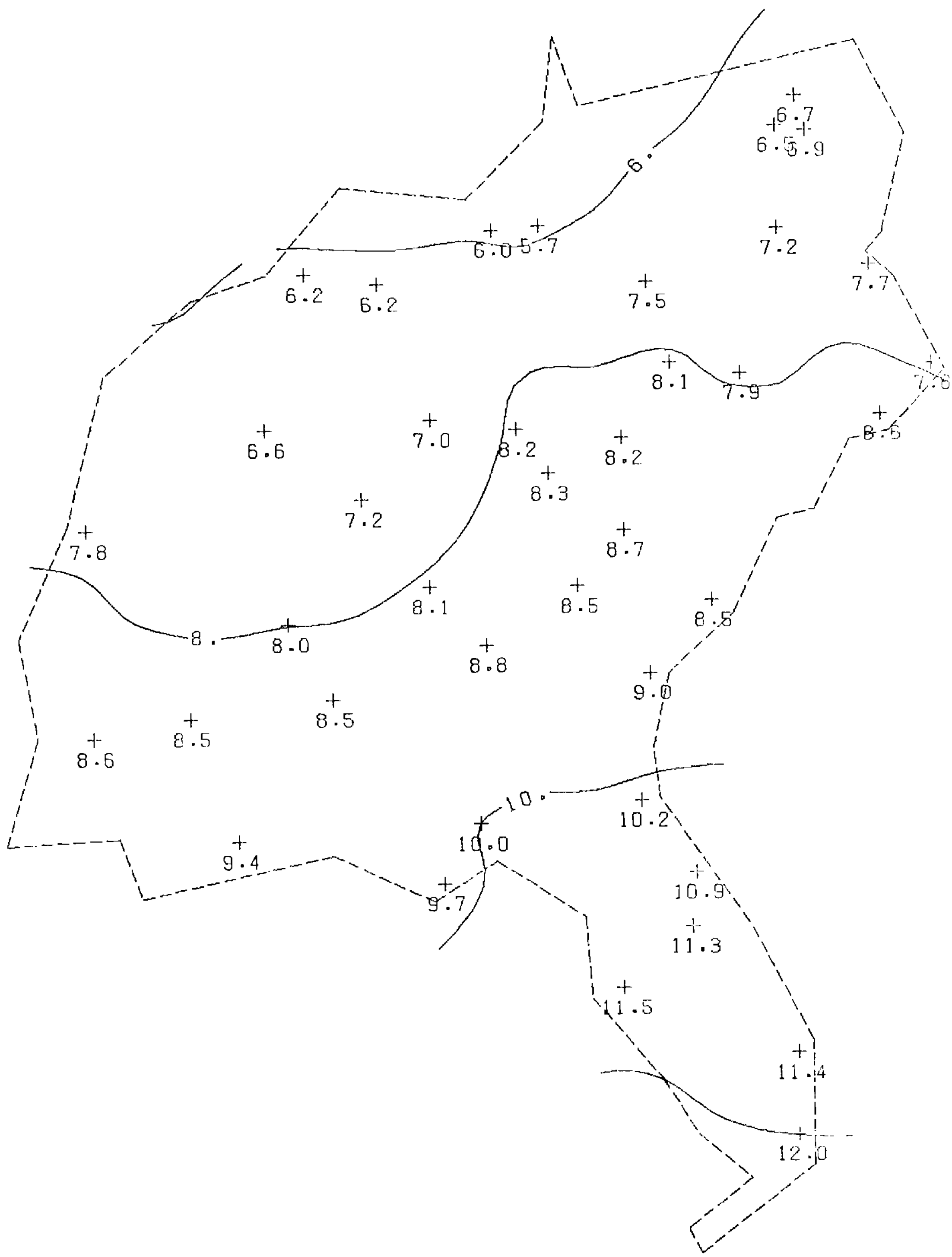

Figure 2.1. Global Horizontal Radiation Megajoules/Square Meter Day - January Average.

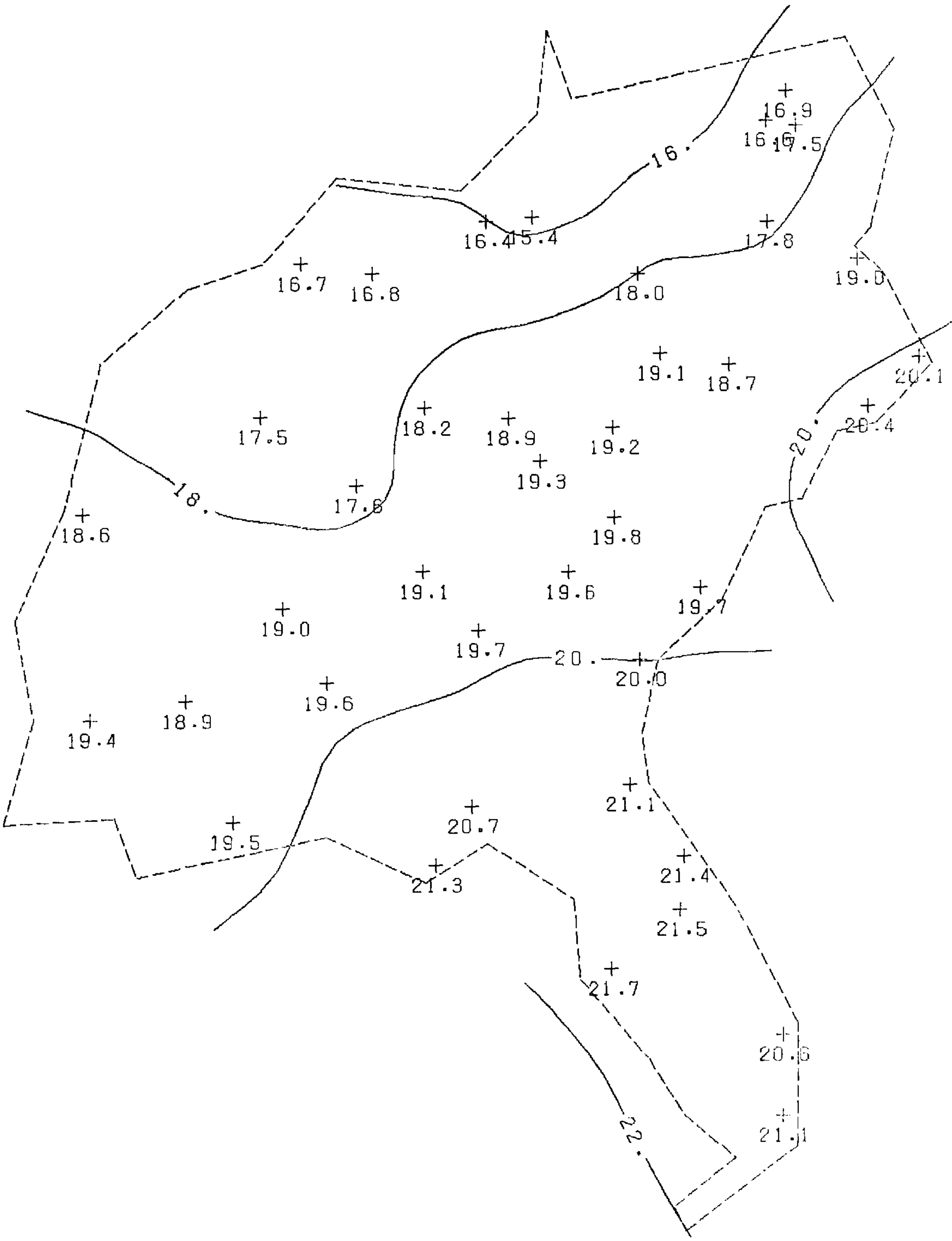

Figure 2.2. Global Horizontal Radiation Megajoules/Square Meter Day - April Average.

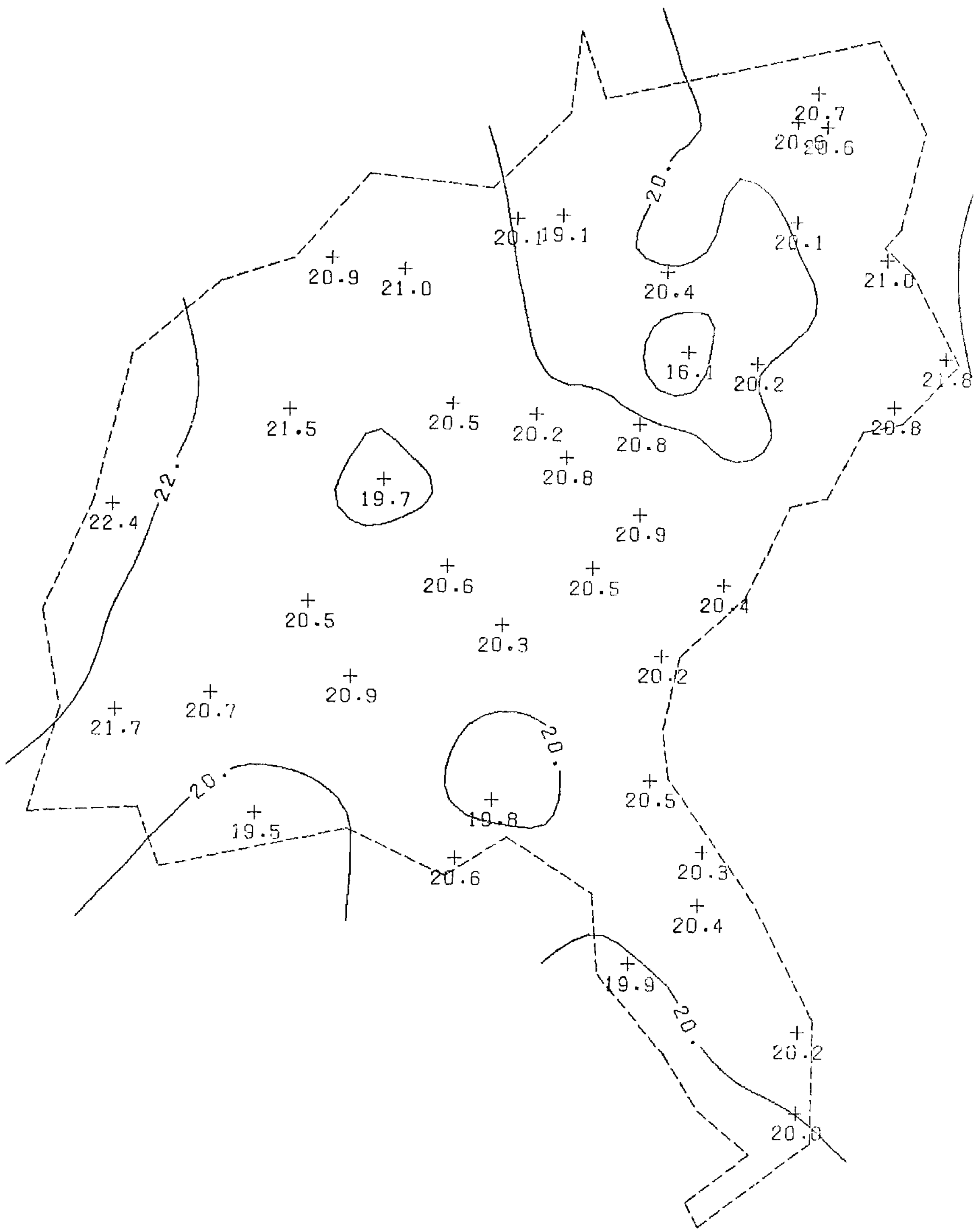

Figure 2.3. Global Horizontal Radiation Megajoules/Square Meter Day - July Average.

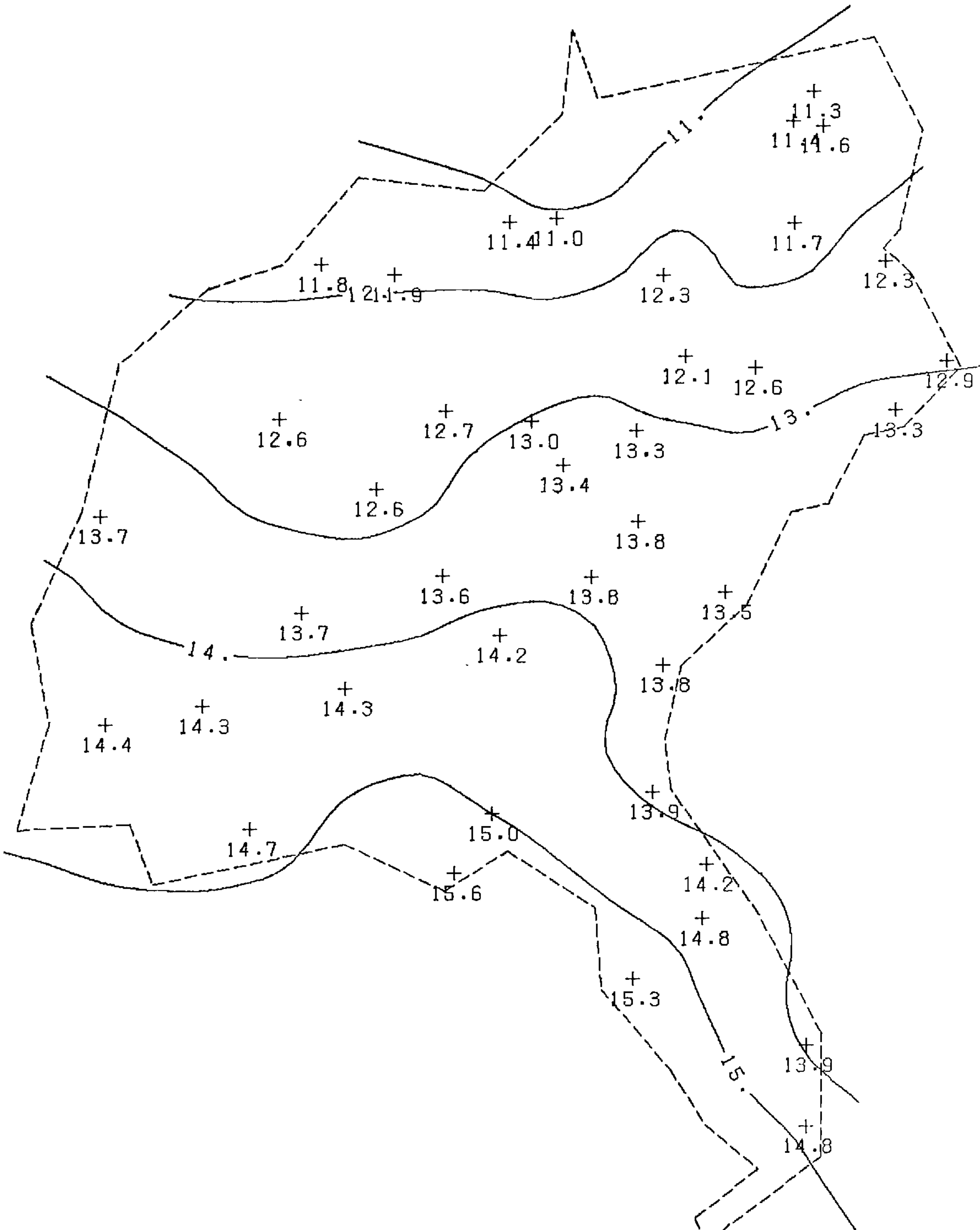

Figure 2.4. Global Horizontal Radiation Megajoules/Square Meter Day - October Average.

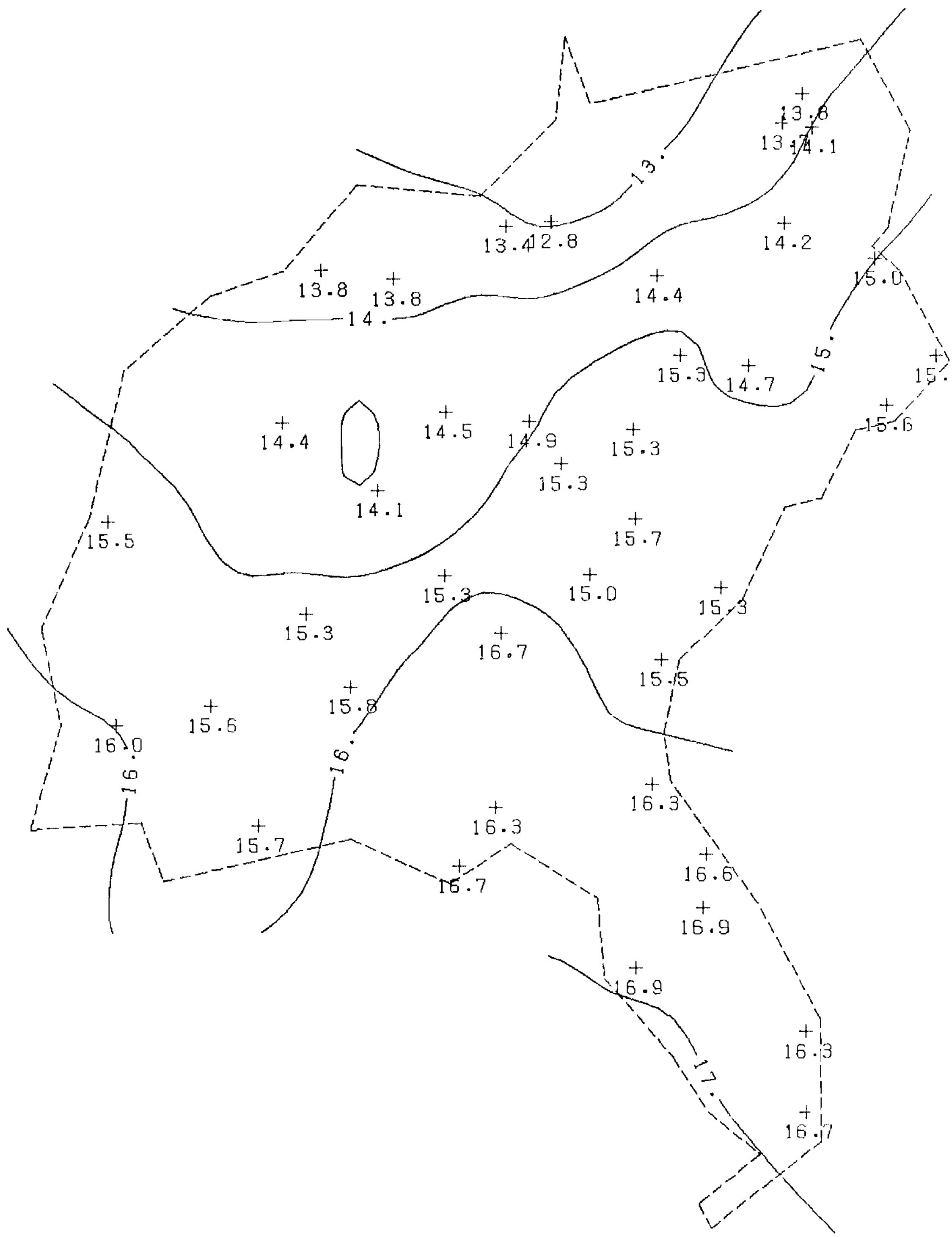

Figure 2.5. **Global Horizontal Radiation Megajoules/Square Meter Day - Annual Average.**

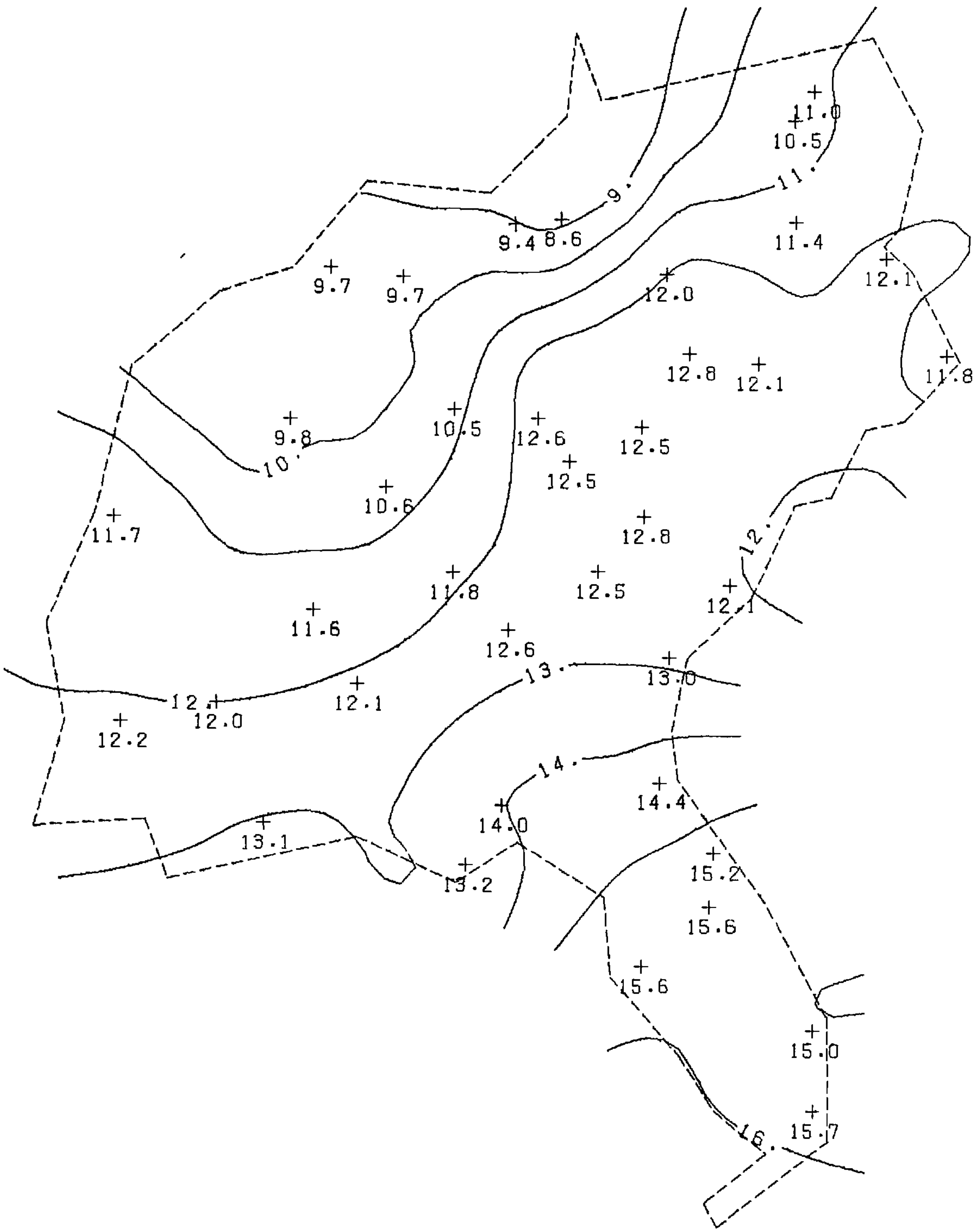

Figure 2.6. Global Radiation on a Latitude Tilted Surface
Megajoules/Square Meter Day - January Average.

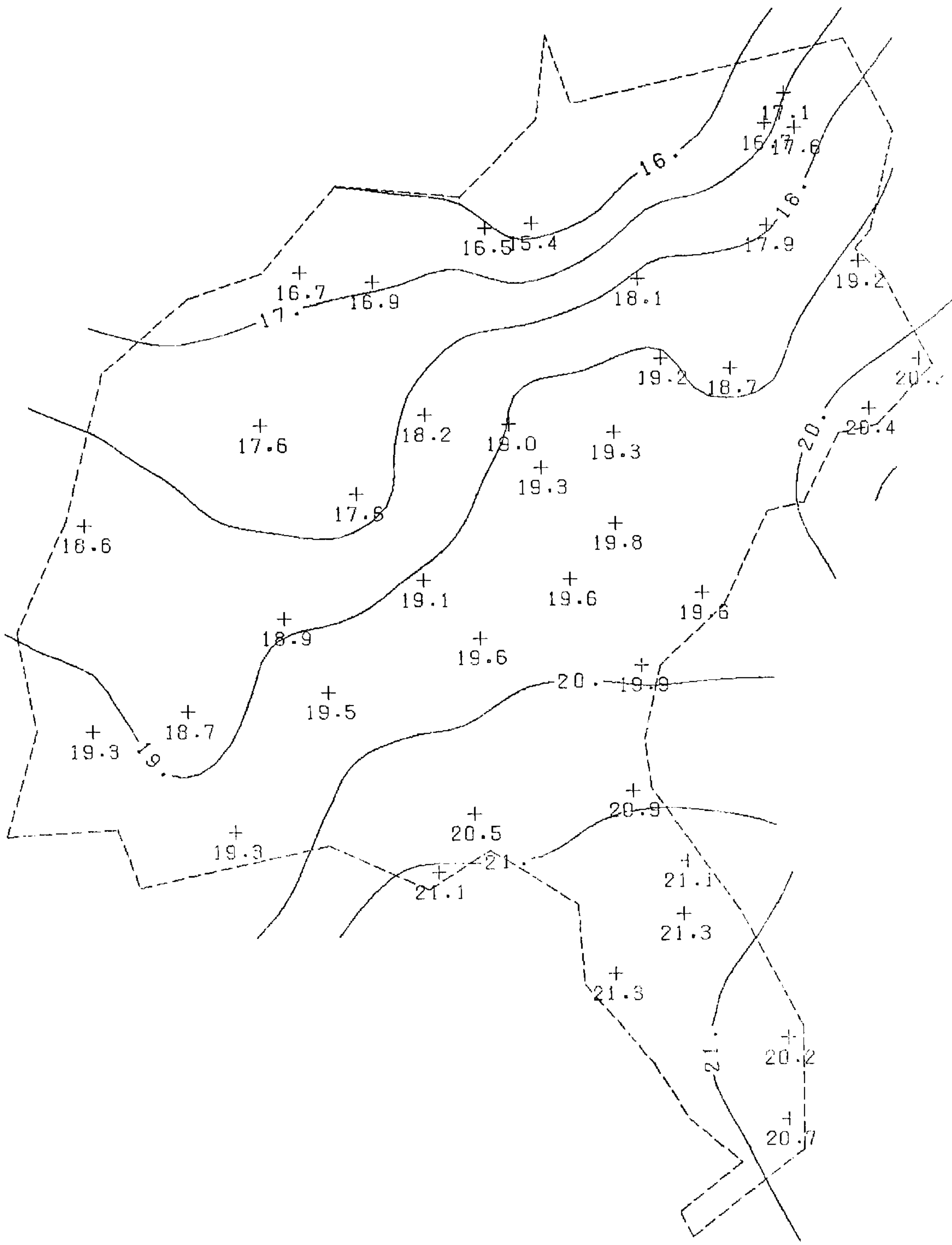

Figure 2.7. Global Radiation on a Latitude Tilted Surface Megajoules/Square Meter Day - April Average.

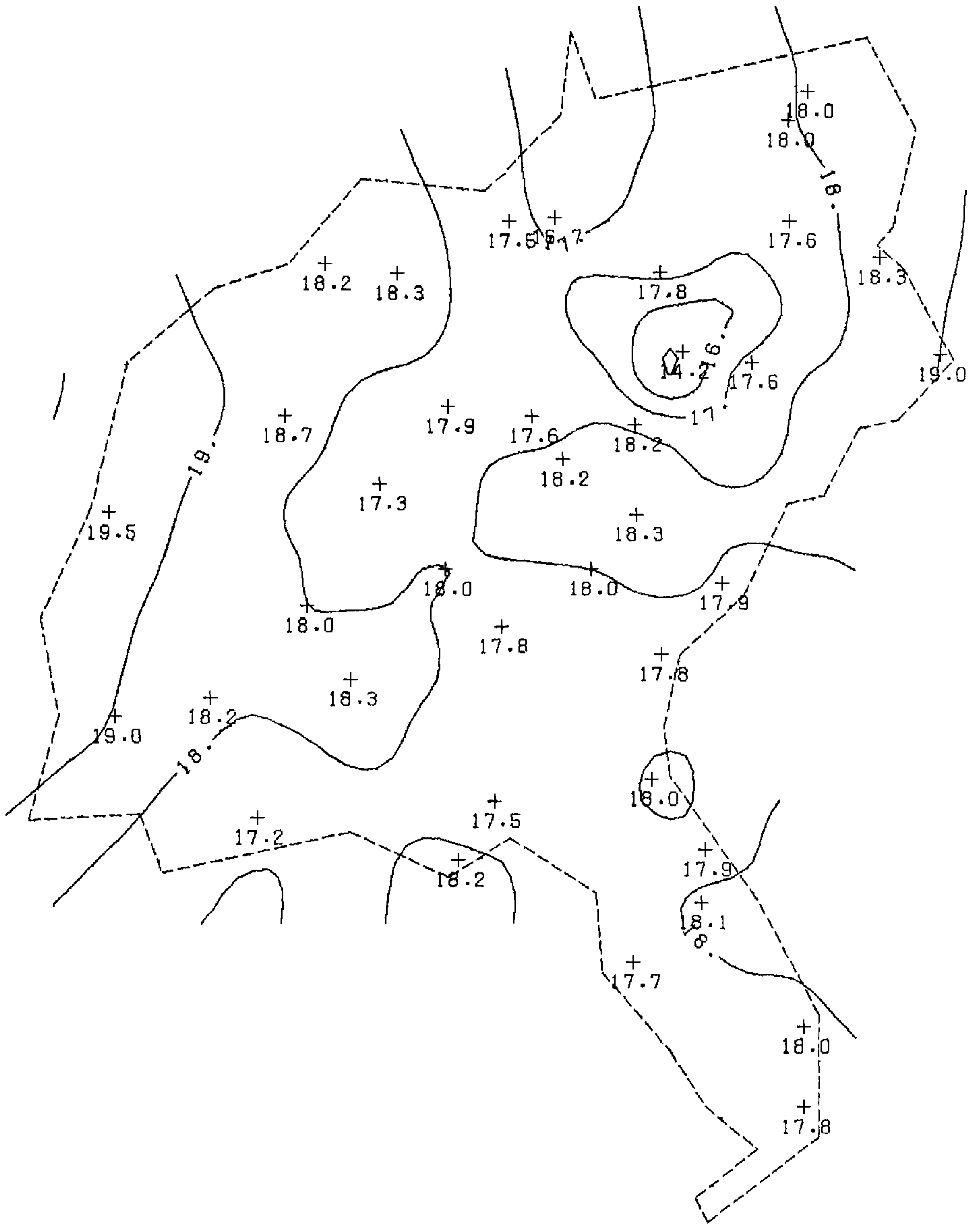

Figure 2.8. Global Radiation on a Latitude Tilted Surface Megajoules/Square Meter Day - July Average.

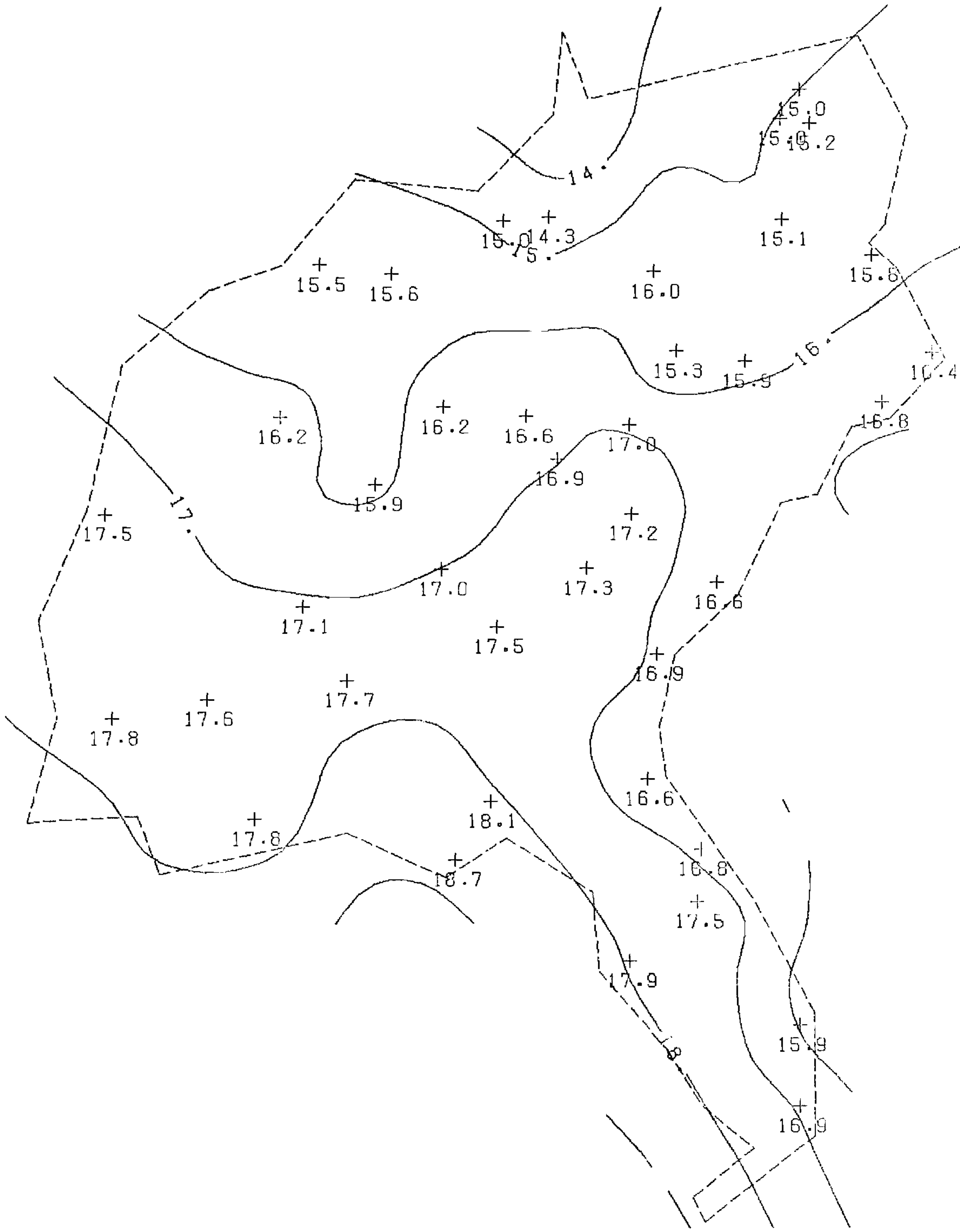

Figure 2.9. Global Radiation on a Latitude Tilted Surface
Megajoules/Square Meter Day - October Average.

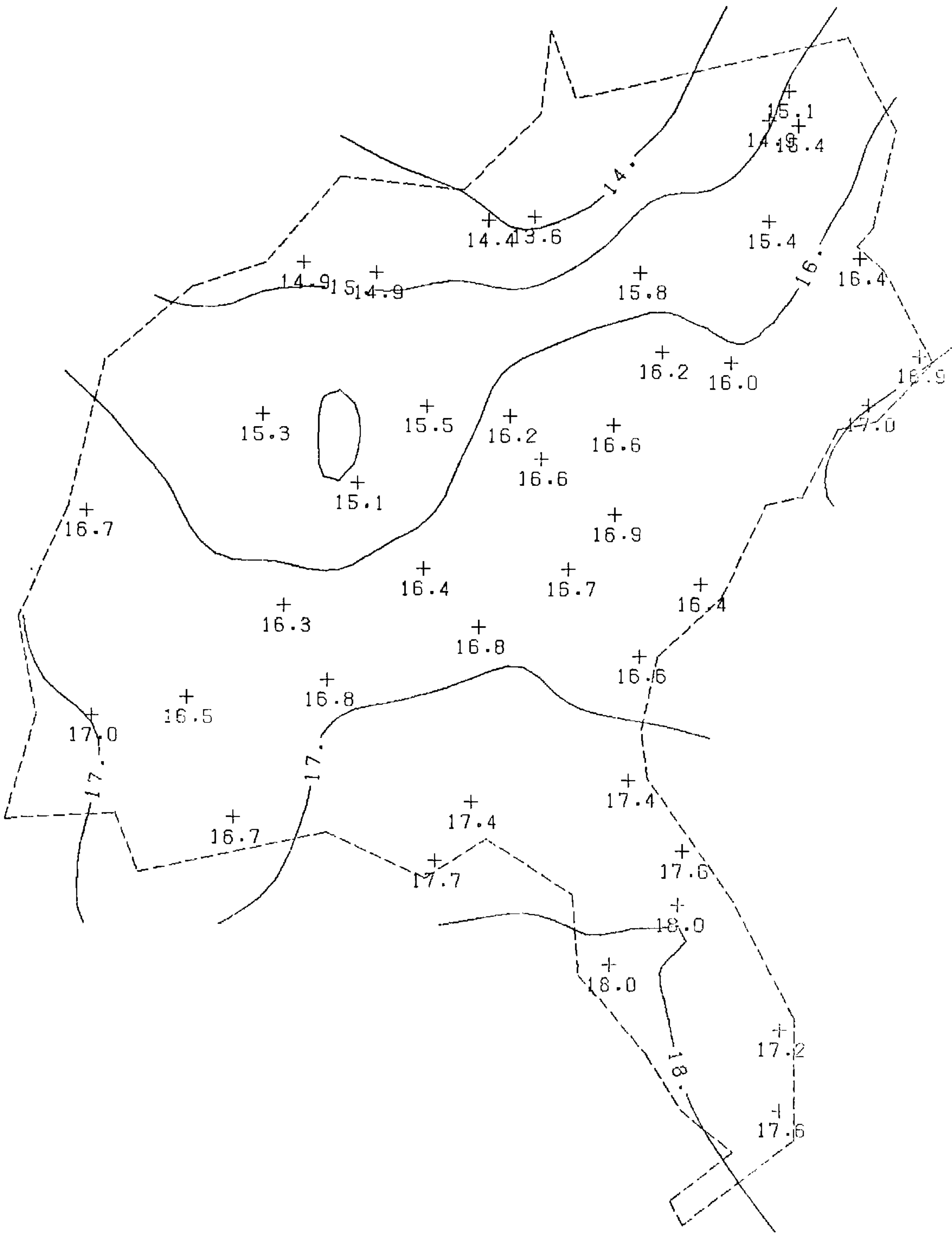

Figure 2.10. Global Radiation on a Latitude Tilted Surface Megajoules/Square Meter Day - Annual Average.

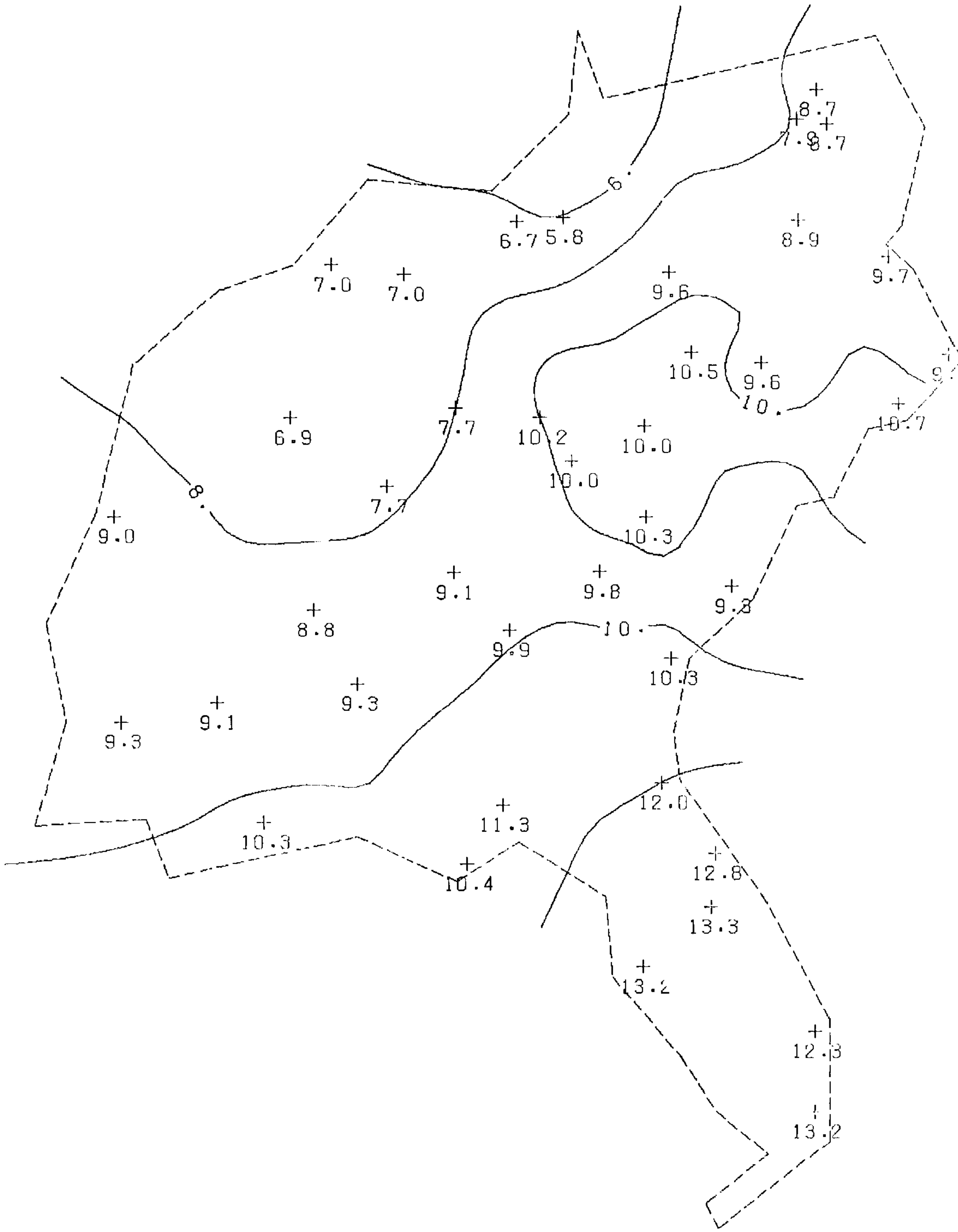

Figure 2.11. Direct Normal Radiation Megajoules/Square Meter Day - January Average.

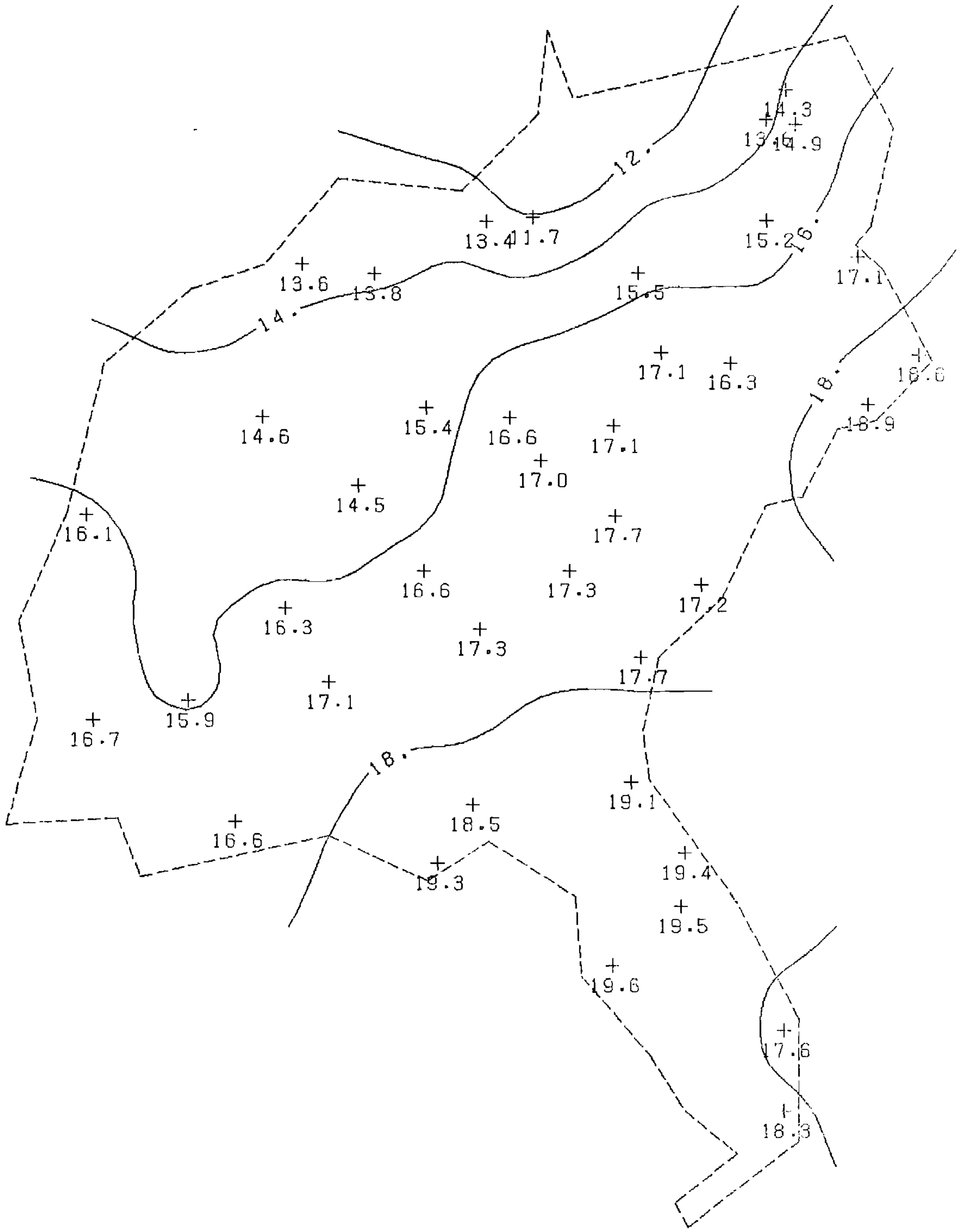

Figure 2.12. Direct Normal Radiation Megajoules/Square Meter Day - April Average.

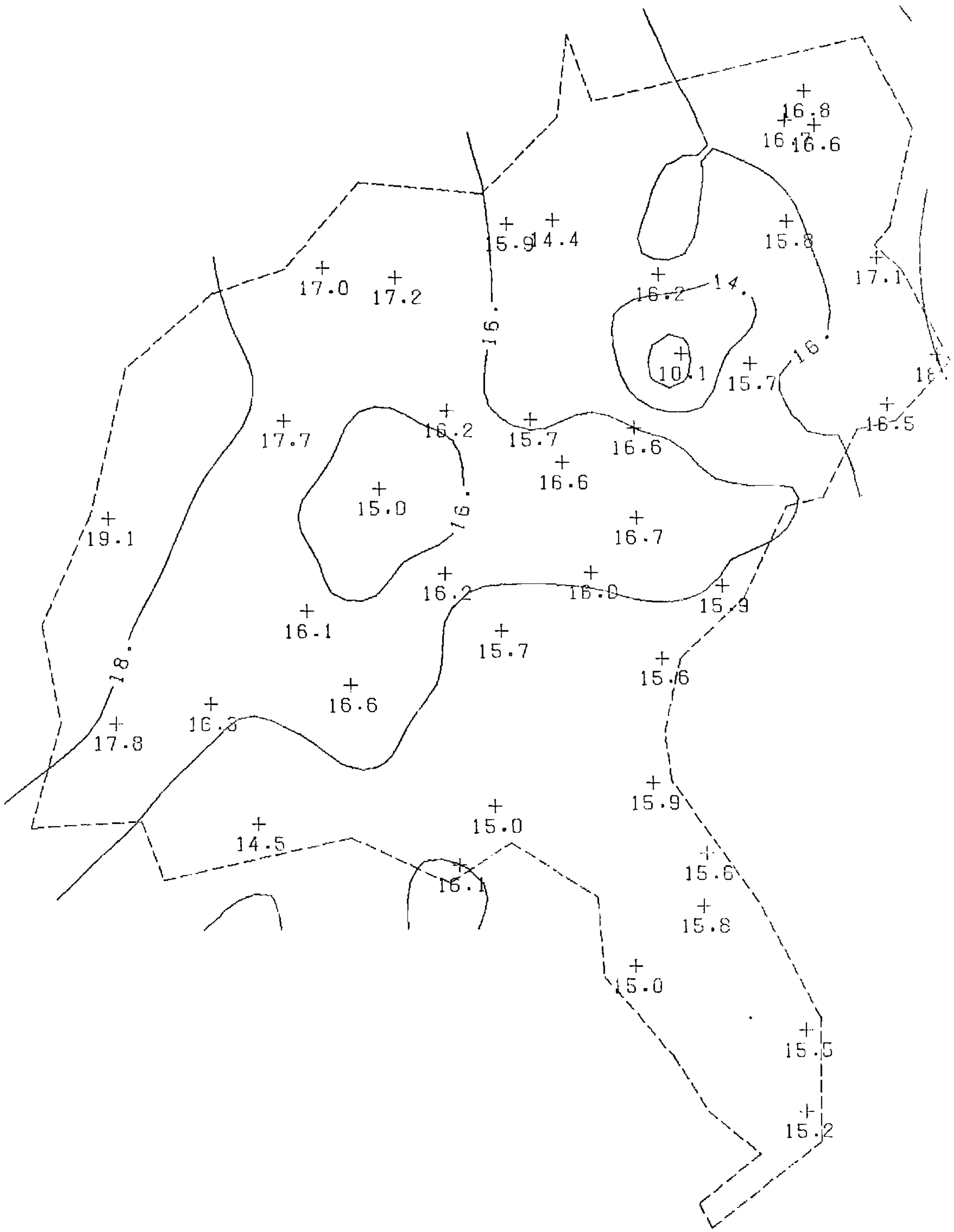

Figure 2.13. Direct Normal Radiation Megajoules/Square Meter Day - July Average.

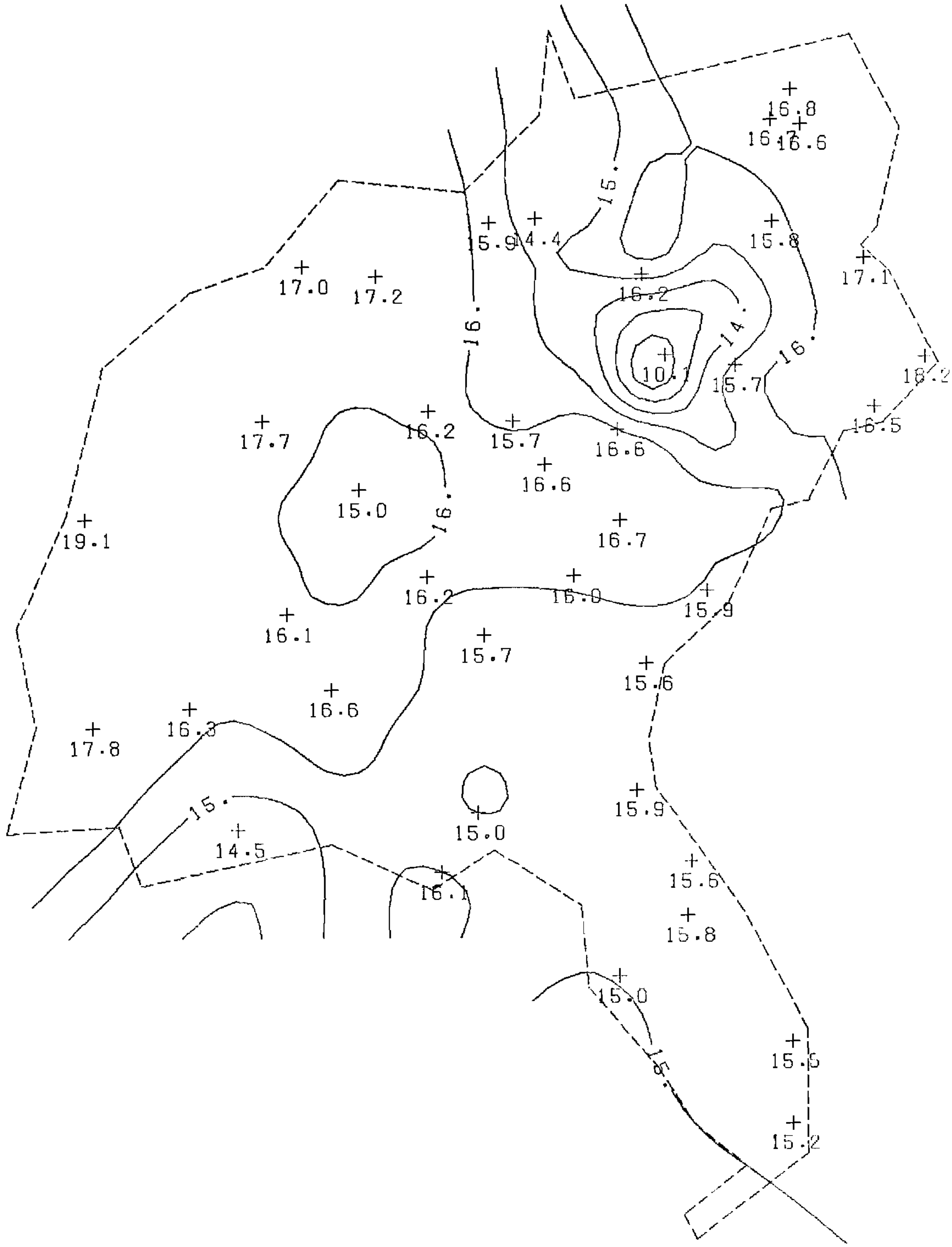

Figure 2.14. Direct Normal Radiation Megajoules/Square Meter Day - October Average.

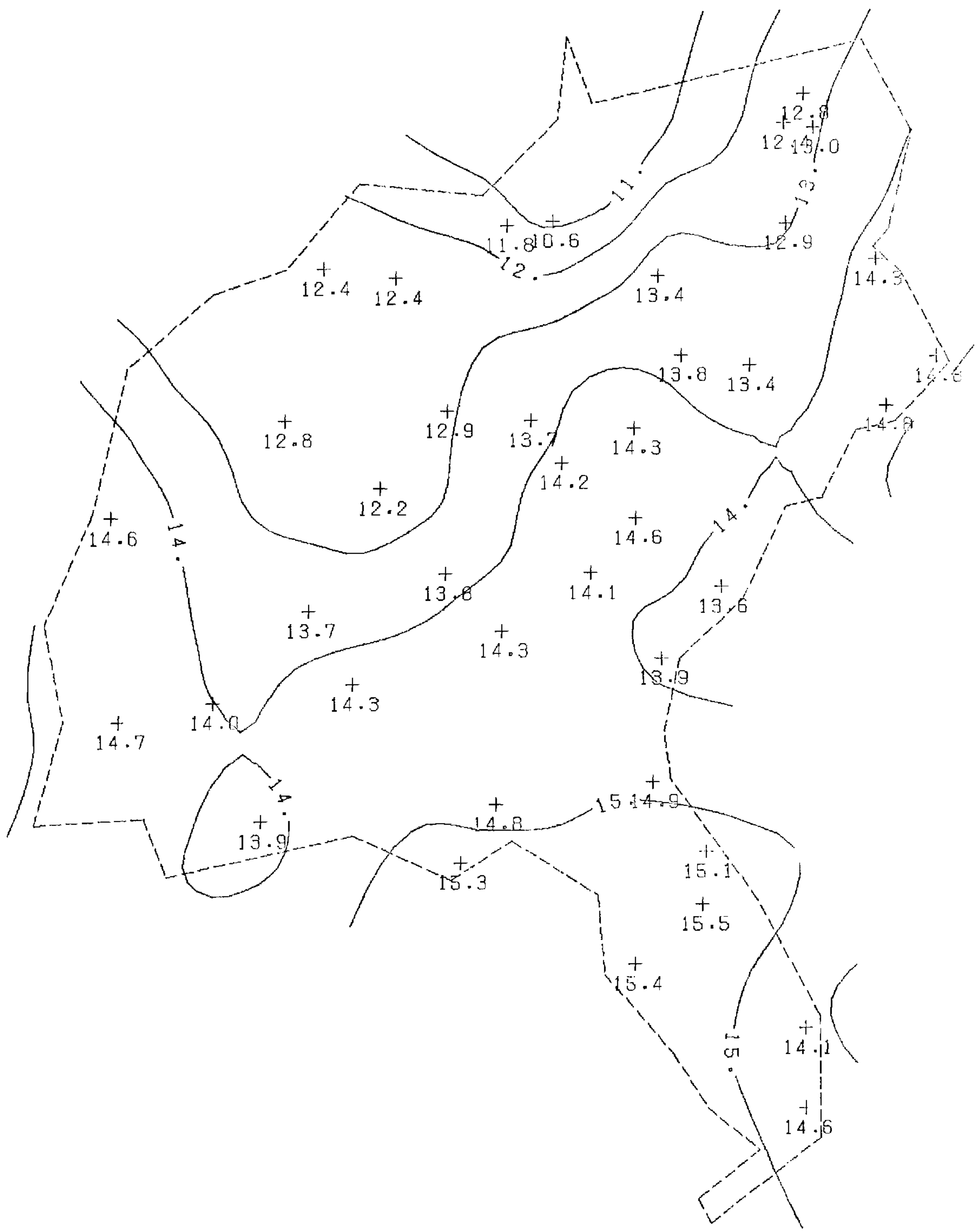

Figure 2.15. Direct Normal Radiation Megajoules/Square Meter Day - Annual Average.

3. WATTS DATA

The Watt report (1978) details a method to calculate the amount of solar radiation available at a location as a function of latitude, longitude, time of year, albedo, cloud cover, precipitable water content, ozone absorption, surface pressure, and turbidity, due to both the stratospheric dust layer and surface aerosols. Where applicable, climatological values for these quantities as given in the Watts report were used to calculate direct, diffuse, and global insolation for Atlanta, Miami, and Washington, D.C. under clear sky and average cloud cover conditions for several reference situations including tilted surfaces (through the use of the Liu and Jordan model and diffuse and direct beam equations presented in the Watts report). Tables 3.1-3.18 show in tabular form and Figures 3.1-3.18 in 3-D graphic form the values calculated from the Watts report for Atlanta for the diffuse and direct components, and global radiation on the horizontal as well as a number of tilt angles, including a latitude tilt. The hourly and daily totals here were calculated using monthly averaged precipitable water, ozone, turbidities, and sky cover. Mid-month positions of the earth were used to determine earth-sun distances and solar declination angles. Albedo was taken to be constant at 0.2. All these were calculated for clear sky and average cloud cover conditions. These calculations were repeated for Miami and Washington, D. C. and presented in Tables 3.19-3.36 and Figures 3.19-3.36 and in Tables 3.37-3.54 and Figures 3.37-3.54, respectively.

Table 3.1. **ATLANTA**

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		TILT ANGLE (DEGREES)																		
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	1	12.4	13.9	15.2	16.5	17.6	18.6	19.5	20.3	21.0	21.5	21.8	22.0	22.1	22.0	21.7	21.4	20.8	20.2	19.4
	2	16.4	17.8	19.1	20.3	21.3	22.2	22.9	23.5	24.0	24.2	24.4	24.3	24.1	23.8	23.2	22.6	21.8	20.8	19.7
	3	21.8	23.0	23.9	24.8	25.4	26.0	26.3	26.5	26.5	26.3	26.0	25.5	24.8	24.0	23.0	21.9	20.6	19.3	17.8
	4	25.9	26.5	27.0	27.2	27.3	27.3	27.0	26.6	26.1	25.3	24.5	23.4	22.3	21.0	19.6	18.1	16.5	14.8	13.0
	5	28.9	29.0	29.0	28.8	28.5	28.0	27.3	26.4	25.4	24.3	23.0	21.7	20.2	18.6	16.9	15.2	13.5	11.7	10.0
MONTH	6	29.6	29.6	29.3	28.9	28.4	27.6	26.8	25.7	24.6	23.3	21.9	20.4	18.8	17.2	15.5	13.8	12.0	10.3	8.8
	7	28.3	28.3	28.2	27.9	27.4	26.8	26.0	25.1	24.1	22.9	21.7	20.3	18.8	17.3	15.7	14.0	12.4	10.7	9.1
	8	26.3	26.7	26.8	26.9	26.7	26.4	26.0	25.4	24.7	23.8	22.8	21.6	20.4	19.0	17.6	16.1	14.5	12.9	11.2
	9	22.6	23.4	24.0	24.5	24.8	25.0	25.0	24.9	24.6	24.2	23.7	22.9	22.1	21.1	20.0	18.8	17.5	16.1	14.6
	10	17.5	18.6	19.6	20.4	21.2	21.8	22.3	22.6	22.8	22.8	22.7	22.5	22.1	21.6	20.9	20.1	19.2	18.2	17.0
	11	14.0	15.5	16.8	18.1	19.2	20.2	21.1	21.8	22.4	22.8	23.1	23.2	23.2	23.0	22.6	22.1	21.5	20.7	19.8
	12	11.8	13.3	14.7	16.0	17.3	18.4	19.3	20.2	20.9	21.5	21.9	22.2	22.3	22.3	22.1	21.8	21.3	20.7	19.9
ANNUAL MEAN		21.3	22.1	22.8	23.4	23.8	24.0	24.1	24.1	23.9	23.6	23.1	22.5	21.8	20.9	19.9	18.8	17.6	16.4	15.0

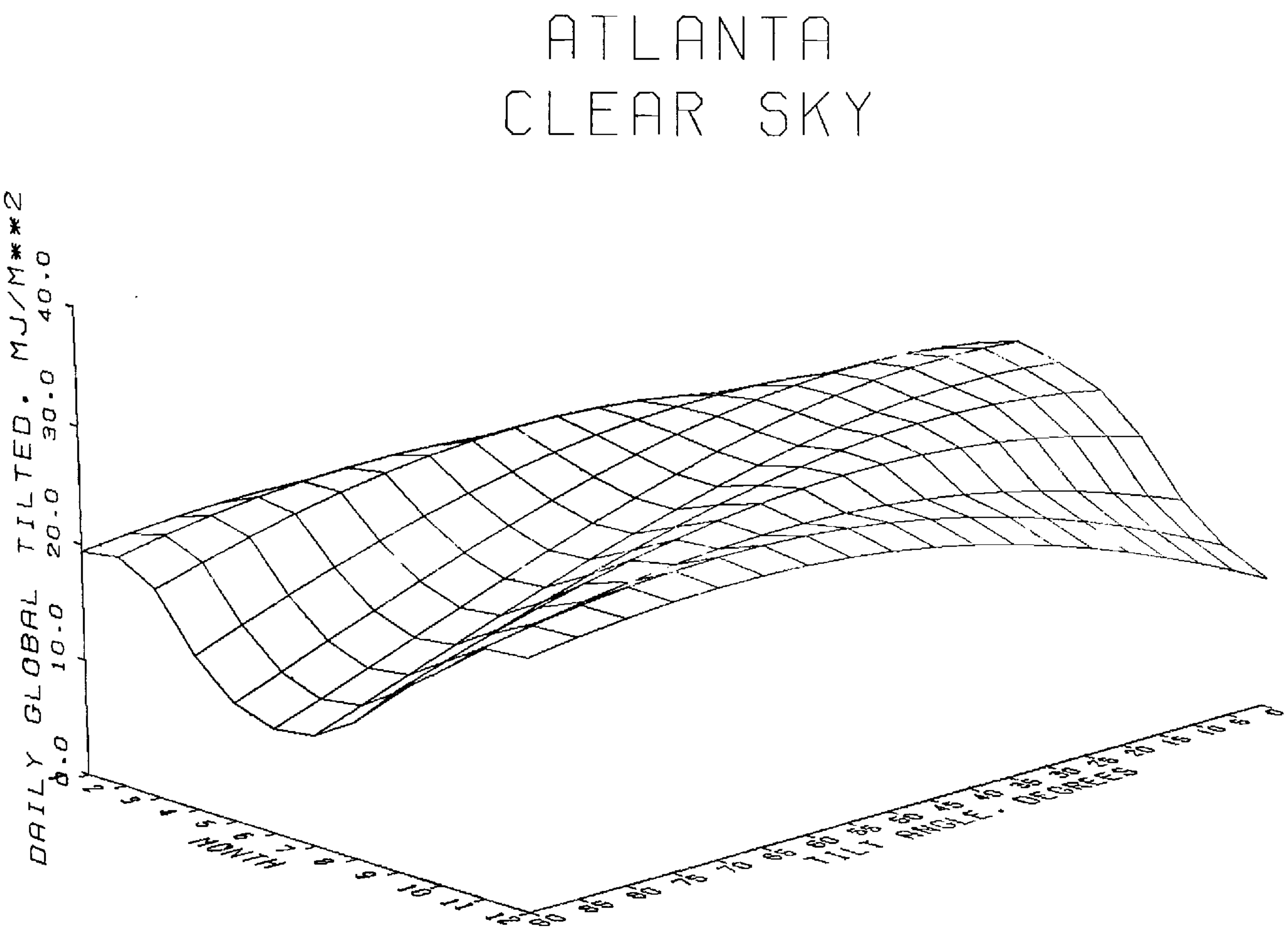

Figure 3.1. Atlanta Clear Sky Daily Global Tilted Ratiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.2. **ATLANTA**

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

TILT ANGLE (DEGREES)

MONTH	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
1	7.9	8.5	9.0	9.5	9.9	10.3	10.6	10.9	11.1	11.2	11.3	11.3	11.3	11.1	11.0	10.7	10.4	10.0	9.6
2	10.7	11.3	11.9	12.4	12.8	13.2	13.4	13.7	13.8	13.8	13.8	13.7	13.5	13.2	12.9	12.5	12.0	11.5	10.8
3	13.7	14.2	14.6	14.9	15.2	15.3	15.4	15.4	15.3	15.1	14.9	14.6	14.1	13.7	13.1	12.5	11.8	11.0	10.2
4	18.3	18.6	18.9	19.0	19.0	18.9	18.7	18.4	18.0	17.5	16.9	16.3	15.5	14.7	13.8	12.8	11.8	10.7	9.6
5	20.7	20.7	20.7	20.6	20.3	20.0	19.5	19.0	18.3	17.5	16.7	15.8	14.8	13.8	12.7	11.6	10.4	9.3	8.1
6	20.9	20.9	20.7	20.4	20.1	19.6	19.1	18.4	17.7	16.8	15.9	15.0	14.0	12.9	11.8	10.7	9.6	8.5	7.5
7	19.4	19.4	19.3	19.1	18.8	18.4	17.9	17.4	16.7	16.0	15.2	14.4	13.5	12.5	11.5	10.5	9.5	8.5	7.5
8	18.5	18.7	18.8	18.7	18.6	18.4	18.1	17.7	17.2	16.6	16.0	15.2	14.4	13.6	12.6	11.7	10.6	9.6	8.6
9	15.7	16.1	16.4	16.7	16.8	16.8	16.8	16.7	16.5	16.1	15.8	15.3	14.7	14.1	13.4	12.6	11.8	10.9	10.0
10	12.6	13.3	13.8	14.3	14.7	15.0	15.2	15.4	15.4	15.4	15.2	15.0	14.7	14.4	13.9	13.3	12.7	12.1	11.3
11	9.8	10.5	11.2	11.8	12.3	12.8	13.2	13.5	13.8	13.9	14.0	14.0	13.9	13.7	13.5	13.1	12.7	12.2	11.7
12	7.7	8.3	8.9	9.4	9.9	10.4	10.7	11.1	11.3	11.5	11.6	11.6	11.6	11.5	11.4	11.1	10.8	10.5	10.1
ANNUAL MEAN	14.6	15.0	15.3	15.6	15.7	15.8	15.7	15.6	15.4	15.1	14.8	14.3	13.8	13.3	12.6	11.9	11.2	10.4	9.6

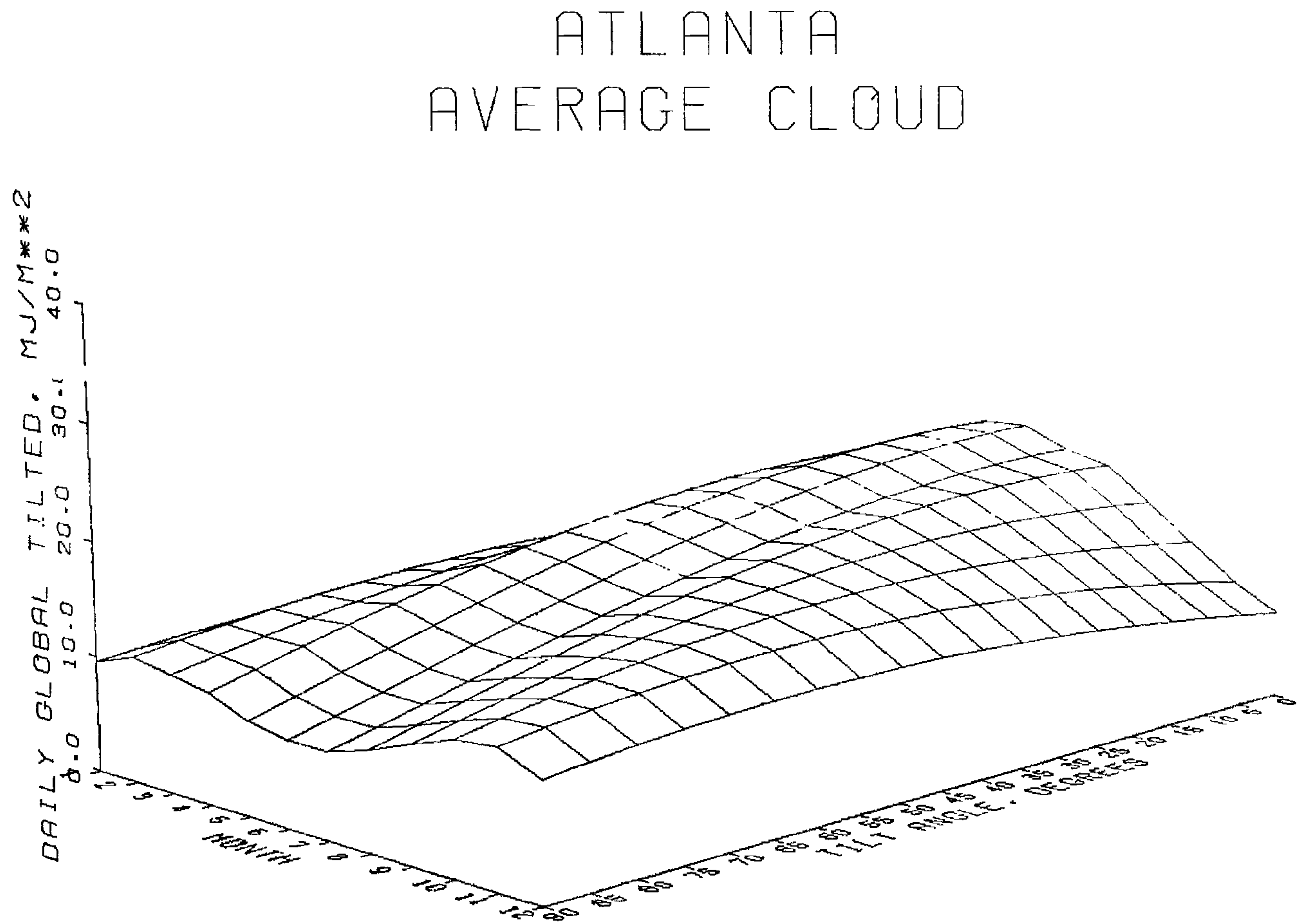

Figure 3.2. Atlanta Average Cloud Daily Global Tilted Radiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.3. ATLANTA

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

MONTH

HOUR		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.003	.008	.001	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.001	.046	.124	.150	.111	.058	.019	.002	0.000	0.000
	8	.003	.019	.090	.214	.298	.335	.317	.266	.198	.114	.041	.008
	9	.099	.148	.229	.348	.432	.483	.488	.449	.379	.284	.174	.110
	10	.213	.254	.323	.448	.535	.598	.624	.591	.514	.405	.265	.205
	11	.284	.324	.389	.519	.610	.683	.725	.696	.610	.487	.323	.263
HOUR	12	.328	.368	.431	.564	.656	.737	.790	.762	.668	.534	.356	.296
	13	.346	.388	.450	.581	.673	.758	.818	.790	.689	.547	.365	.308
	14	.340	.385	.446	.571	.660	.746	.807	.778	.671	.526	.350	.298
	15	.311	.359	.418	.533	.617	.700	.759	.727	.617	.470	.312	.266
	16	.255	.308	.367	.467	.545	.623	.674	.638	.524	.379	.247	.211
	17	.166	.230	.290	.374	.446	.516	.554	.511	.393	.248	.145	.121
	18	.038	.109	.182	.250	.316	.376	.399	.345	.216	.070	.018	.012
	19	0.000	.004	.036	.082	.147	.202	.207	.136	.028	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.008	.027	.026	.003	0.000	0.000	0.000	0.000
DAILY TOTAL		2.38	2.90	3.65	5.00	6.07	6.94	7.30	6.75	5.53	4.07	2.60	2.10

Figure 3.3. Atlanta Clear Sky Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.4. ATLANTA

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.003	.008	.001	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.001	.052	.140	.164	.116	.059	.020	.002	0.000	0.000
	8	.003	.022	.120	.265	.356	.384	.350	.292	.221	.129	.050	.009
	9	.135	.212	.346	.450	.529	.565	.551	.506	.443	.341	.246	.163
	10	.328	.395	.512	.590	.662	.707	.711	.674	.611	.498	.398	.338
	11	.458	.522	.629	.690	.758	.810	.829	.796	.730	.605	.499	.453
HOUR	12	.538	.601	.703	.751	.817	.875	.904	.874	.802	.666	.555	.521
	13	.572	.637	.736	.775	.838	.900	.936	.906	.827	.683	.571	.544
	14	.562	.631	.728	.760	.822	.885	.924	.892	.806	.656	.546	.524
	15	.506	.583	.679	.708	.767	.831	.868	.833	.738	.583	.479	.461
	16	.403	.492	.589	.617	.676	.737	.769	.729	.624	.464	.367	.351
	17	.245	.351	.453	.487	.547	.606	.629	.579	.460	.294	.199	.181
	18	.047	.150	.265	.314	.379	.435	.446	.383	.243	.078	.021	.015
	19	0.000	.004	.044	.095	.167	.225	.223	.144	.029	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.008	.028	.026	.003	0.000	0.000	0.000	0.000
DAILY TOTAL		3.80	4.60	5.81	6.55	7.47	8.16	8.28	7.67	6.55	5.00	3.93	3.56

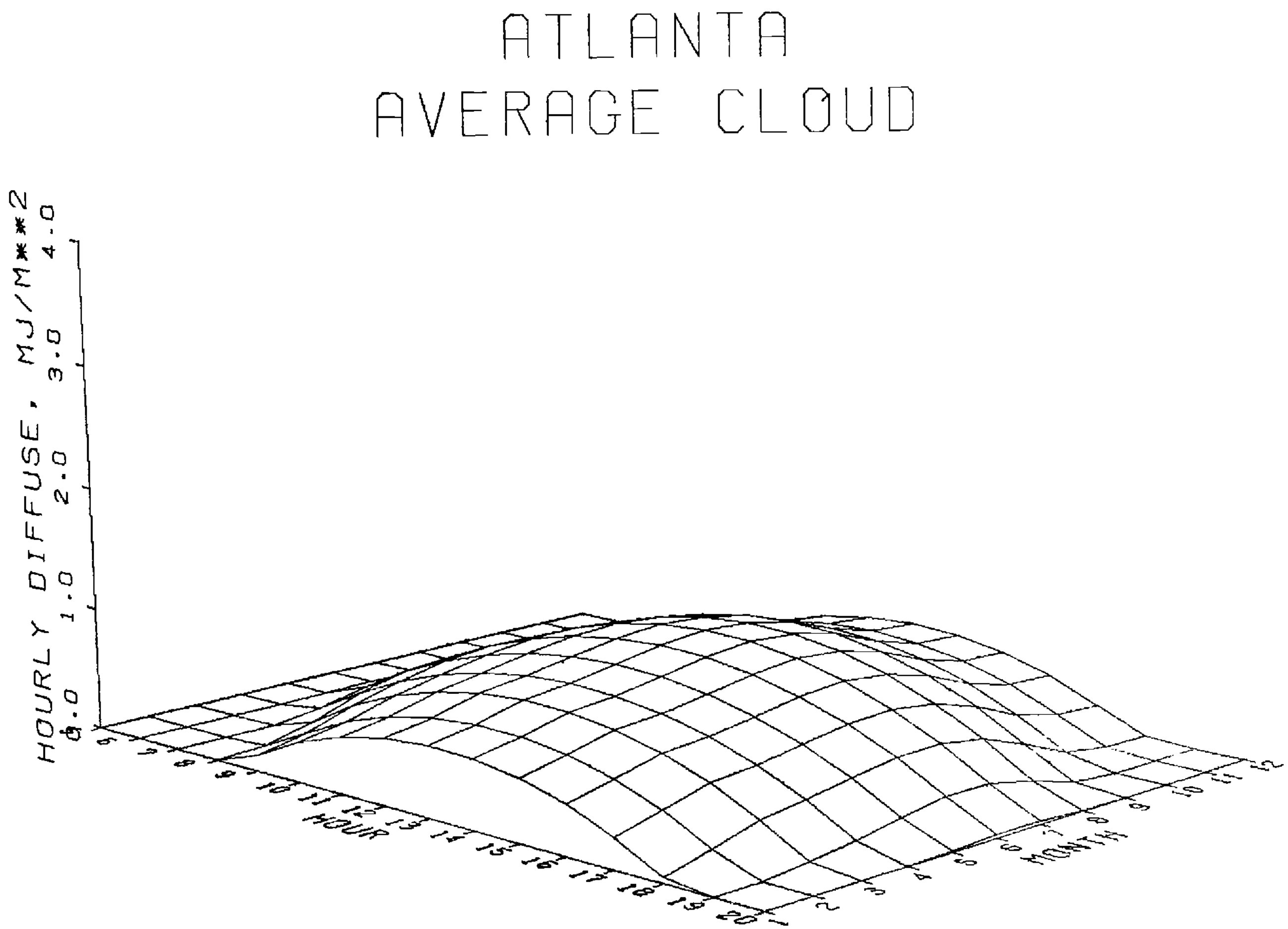

Figure 3.4. Atlanta Average Cloud Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.5. ATLANTA

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.030	.060	.010	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.009	.444	.976	.991	.658	.364	.144	.017	0.000	0.000
	8	.043	.250	1.079	1.769	1.991	1.886	1.604	1.445	1.270	.914	.536	.126
	9	1.232	1.735	2.328	2.464	2.509	2.377	2.151	2.100	2.083	1.950	1.990	1.536
	10	2.301	2.570	2.860	2.821	2.797	2.660	2.469	2.464	2.504	2.454	2.655	2.494
	11	2.760	2.950	3.126	3.015	2.960	2.825	2.656	2.671	2.731	2.713	2.967	2.896
HOUR	12	2.980	3.135	3.260	3.116	3.047	2.915	2.759	2.783	2.847	2.838	3.109	3.084
	13	3.061	3.208	3.313	3.152	3.076	2.947	2.800	2.826	2.885	2.869	3.144	3.142
	14	3.036	3.197	3.300	3.130	3.053	2.928	2.785	2.808	2.853	2.817	3.086	3.094
	15	2.898	3.097	3.219	3.046	2.974	2.855	2.712	2.726	2.745	2.665	2.911	2.920
	16	2.585	2.871	3.042	2.878	2.821	2.712	2.566	2.561	2.530	2.360	2.542	2.542
	17	1.914	2.409	2.695	2.571	2.553	2.466	2.316	2.271	2.131	1.766	1.712	1.661
	18	.500	1.336	1.968	1.987	2.071	2.041	1.889	1.755	1.367	.582	.245	.194
	19	0.000	.054	.452	.771	1.135	1.279	1.143	.813	.206	0.000	0.000	0.000
	20	0.000	0.000	0.000	.002	.071	.200	.164	.023	0.000	0.000	0.000	0.000
DAILY TOTAL		23.31	26.81	30.65	31.17	32.06	31.14	28.68	27.61	26.30	23.95	24.90	23.69

Figure 3.5. Atlanta Clear Sky Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.6. ATLANTA

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.017	.034	.005	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.004	.249	.564	.556	.347	.201	.077	.010	0.000	0.000
	8	.018	.113	.468	.992	1.151	1.058	.845	.798	.680	.521	.274	.054
	9	.503	.782	1.009	1.382	1.450	1.334	1.134	1.160	1.115	1.111	1.015	.653
	10	.939	1.158	1.240	1.582	1.616	1.492	1.301	1.361	1.341	1.398	1.354	1.060
	11	1.126	1.329	1.355	1.691	1.711	1.585	1.400	1.476	1.462	1.545	1.513	1.231
HOUR	12	1.216	1.412	1.413	1.748	1.761	1.635	1.454	1.538	1.525	1.616	1.586	1.311
	13	1.249	1.445	1.436	1.768	1.778	1.653	1.475	1.561	1.545	1.634	1.604	1.335
	14	1.239	1.440	1.431	1.756	1.765	1.643	1.468	1.551	1.528	1.604	1.574	1.315
	15	1.182	1.395	1.395	1.709	1.719	1.601	1.429	1.506	1.470	1.518	1.485	1.241
	16	1.055	1.293	1.319	1.615	1.631	1.521	1.352	1.415	1.355	1.344	1.296	1.080
	17	.781	1.085	1.168	1.443	1.476	1.383	1.221	1.255	1.141	1.006	.873	.706
	18	.204	.602	.853	1.115	1.197	1.145	.995	.970	.732	.332	.125	.083
	19	0.000	.024	.196	.432	.656	.717	.603	.449	.110	0.000	0.000	0.000
	20	0.000	0.000	0.000	.001	.041	.112	.087	.012	0.000	0.000	0.000	0.000
DAILY TOTAL		9.51	12.08	13.29	17.43	18.53	17.47	15.12	15.25	14.08	13.64	12.70	10.07

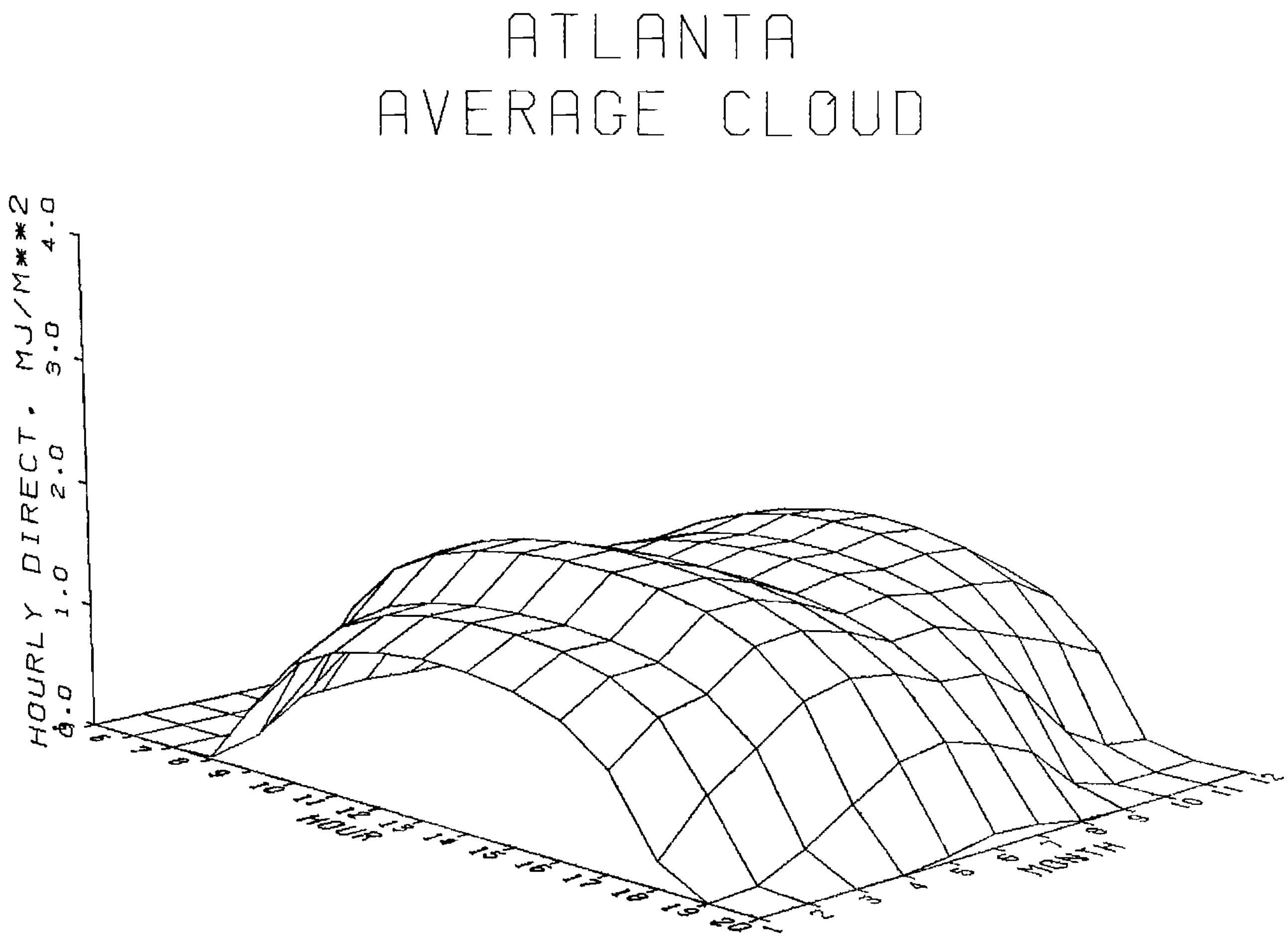

Figure 3.6. Atlanta Average Cloud Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.7. ATLANTA

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.005	.013	.002	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.001	.101	.312	.363	.237	.112	.034	.003	0.000	0.000
	8	.004	.037	.261	.726	1.047	1.084	.908	.724	.520	.281	.096	.014
	9	.293	.525	1.014	1.535	1.844	1.861	1.680	1.514	1.301	.976	.666	.370
	10	.922	1.246	1.796	2.290	2.565	2.567	2.398	2.261	2.047	1.672	1.327	.995
	11	1.496	1.879	2.448	2.894	3.133	3.130	2.980	2.866	2.644	2.223	1.861	1.530
HOUR	12	1.900	2.328	2.897	3.291	3.500	3.500	3.374	3.274	3.029	2.563	2.191	1.885
	13	2.083	2.544	3.105	3.447	3.636	3.648	3.546	3.447	3.169	2.659	2.284	2.014
	14	2.027	2.509	3.054	3.351	3.529	3.561	3.481	3.372	3.052	2.502	2.132	1.906
	15	1.736	2.226	2.748	3.009	3.189	3.246	3.185	3.056	2.687	2.107	1.748	1.570
	16	1.242	1.720	2.214	2.451	2.642	2.730	2.682	2.524	2.108	1.513	1.175	1.047
	17	.619	1.051	1.499	1.726	1.936	2.056	2.018	1.825	1.370	.799	.500	.423
	18	.087	.339	.700	.918	1.142	1.287	1.256	1.036	.585	.157	.036	.024
	19	0.000	.006	.083	.204	.388	.534	.512	.306	.051	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.013	.049	.045	.005	0.000	0.000	0.000	0.000
DAILY TOTAL		12.41	16.41	21.82	25.94	28.88	29.63	28.30	26.32	22.60	17.46	14.02	11.78

Figure 3.7. Atlanta Clear Sky Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.8. ATLANTA

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.004	.010	.002	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.001	.082	.248	.284	.183	.090	.028	.002	0.000	0.000
	8	.004	.030	.194	.552	.789	.804	.661	.545	.394	.224	.078	.012
	9	.214	.381	.686	1.116	1.345	1.339	1.179	1.095	.936	.735	.497	.273
	10	.617	.842	1.151	1.623	1.835	1.811	1.645	1.596	1.432	1.220	.940	.674
	11	.952	1.222	1.522	2.021	2.217	2.182	2.017	1.996	1.819	1.594	1.283	.992
HOUR	12	1.180	1.483	1.772	2.281	2.461	2.425	2.266	2.262	2.066	1.822	1.491	1.196
	13	1.281	1.608	1.887	2.383	2.551	2.521	2.374	2.374	2.156	1.886	1.550	1.269
	14	1.250	1.588	1.859	2.320	2.480	2.464	2.333	2.326	2.081	1.781	1.454	1.208
	15	1.088	1.425	1.690	2.097	2.254	2.259	2.146	2.120	1.847	1.515	1.211	1.015
	16	.806	1.128	1.390	1.730	1.887	1.919	1.828	1.771	1.472	1.110	.840	.706
	17	.430	.721	.977	1.246	1.409	1.470	1.400	1.305	.983	.608	.380	.309
	18	.068	.253	.489	.689	.856	.946	.898	.765	.441	.127	.030	.020
	19	0.000	.005	.065	.163	.306	.411	.384	.238	.042	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.011	.040	.036	.004	0.000	0.000	0.000	0.000
	DAILY TOTAL	7.89	10.69	13.68	18.30	20.65	20.89	19.35	18.49	15.70	12.62	9.75	7.67

Figure 3.8. Atlanta Average Cloud Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.9. ATLANTA

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.003	.007	.001	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.001	.062	.150	.162	.113	.063	.030	.004	0.000	0.000
	8	.015	.079	.319	.615	.745	.710	.603	.553	.519	.396	.217	.047
	9	.624	.861	1.222	1.473	1.555	1.472	1.347	1.341	1.374	1.287	1.171	.817
	10	1.608	1.829	2.150	2.312	2.330	2.214	2.093	2.137	2.217	2.141	2.081	1.794
	11	2.390	2.630	2.923	2.996	2.958	2.822	2.719	2.801	2.898	2.806	2.773	2.527
HOUR	12	2.918	3.186	3.455	3.450	3.368	3.229	3.148	3.254	3.341	3.213	3.190	2.994
	13	3.152	3.451	3.702	3.629	3.520	3.392	3.337	3.447	3.502	3.328	3.307	3.161
	14	3.080	3.409	3.641	3.519	3.400	3.296	3.265	3.364	3.367	3.140	3.116	3.021
	15	2.704	3.060	3.279	3.128	3.020	2.950	2.941	3.011	2.948	2.666	2.628	2.580
	16	2.050	2.431	2.646	2.494	2.415	2.388	2.397	2.424	2.286	1.946	1.879	1.868
	17	1.163	1.576	1.798	1.683	1.653	1.673	1.694	1.669	1.452	1.066	.921	.912
	18	.216	.586	.846	.811	.838	.901	.929	.853	.589	.226	.090	.076
	19	0.000	.014	.102	.138	.196	.261	.280	.196	.046	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.007	.025	.024	.003	0.000	0.000	0.000	0.000
DAILY TOTAL		19.92	23.11	26.08	26.31	26.16	25.50	24.89	25.12	24.57	22.22	21.37	19.80

Figure 3.9. Atlanta Clear Sky Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.10. ATLANTA

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.003	.007	.001	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.001	.058	.149	.164	.113	.060	.024	.003	0.000	0.000
8	.008	.048	.212	.477	.599	.578	.485	.438	.384	.284	.138	.025
9	.341	.520	.755	1.059	1.154	1.095	.979	.977	.956	.897	.741	.453
10	.876	1.081	1.273	1.607	1.670	1.582	1.453	1.499	1.495	1.464	1.302	.993
11	1.288	1.529	1.689	2.045	2.081	1.974	1.841	1.925	1.922	1.898	1.720	1.387
12	1.561	1.833	1.971	2.333	2.347	2.234	2.106	2.212	2.196	2.162	1.969	1.634
13	1.681	1.978	2.100	2.447	2.446	2.337	2.221	2.335	2.295	2.236	2.039	1.722
14	1.644	1.955	2.068	2.377	2.368	2.276	2.177	2.282	2.212	2.114	1.925	1.648
15	1.451	1.765	1.878	2.129	2.121	2.056	1.978	2.059	1.952	1.807	1.633	1.415
16	1.111	1.418	1.541	1.724	1.726	1.695	1.642	1.684	1.538	1.336	1.179	1.033
17	.637	.937	1.079	1.198	1.220	1.228	1.201	1.194	1.006	.747	.585	.506
18	.117	.356	.537	.614	.664	.710	.705	.648	.432	.163	.057	.041
19	0.000	.009	.071	.123	.188	.248	.252	.172	.037	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	.007	.026	.024	.003	0.000	0.000	0.000	0.000
DAILY TOTAL	10.72	13.43	15.18	18.19	18.74	18.21	17.18	17.49	16.45	15.11	13.29	10.86

Figure 3.10. Atlanta Average Cloud Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.11. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.00	.01	.01	.01	.01	.01	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
9	.29	.35	.41	.46	.51	.56	.60	.64	.67	.70	.73	.75	.77	.78	.78	.78	.78	.76	.75
10	.92	1.05	1.17	1.28	1.39	1.48	1.57	1.64	1.71	1.76	1.80	1.83	1.84	1.85	1.84	1.82	1.78	1.74	1.68
11	1.50	1.67	1.83	1.98	2.11	2.24	2.34	2.44	2.51	2.57	2.61	2.64	2.64	2.63	2.60	2.55	2.49	2.41	2.31
12	1.90	2.10	2.29	2.46	2.61	2.75	2.87	2.97	3.05	3.11	3.15	3.17	3.17	3.14	3.10	3.03	2.94	2.84	2.71
13	2.08	2.30	2.49	2.67	2.84	2.98	3.11	3.21	3.29	3.35	3.39	3.41	3.40	3.37	3.32	3.24	3.14	3.02	2.88
14	2.03	2.24	2.43	2.61	2.77	2.91	3.03	3.14	3.22	3.28	3.32	3.34	3.33	3.30	3.25	3.18	3.08	2.97	2.83
15	1.74	1.92	2.10	2.26	2.41	2.54	2.66	2.76	2.84	2.90	2.94	2.96	2.96	2.94	2.90	2.84	2.76	2.67	2.55
16	1.24	1.39	1.54	1.67	1.80	1.91	2.01	2.09	2.16	2.22	2.26	2.29	2.30	2.30	2.28	2.24	2.19	2.12	2.04
17	.62	.72	.81	.90	.98	1.06	1.13	1.19	1.24	1.29	1.32	1.35	1.37	1.38	1.38	1.37	1.35	1.32	1.29
18	.09	.11	.13	.15	.17	.19	.21	.22	.24	.25	.26	.27	.28	.28	.29	.29	.29	.28	.28
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

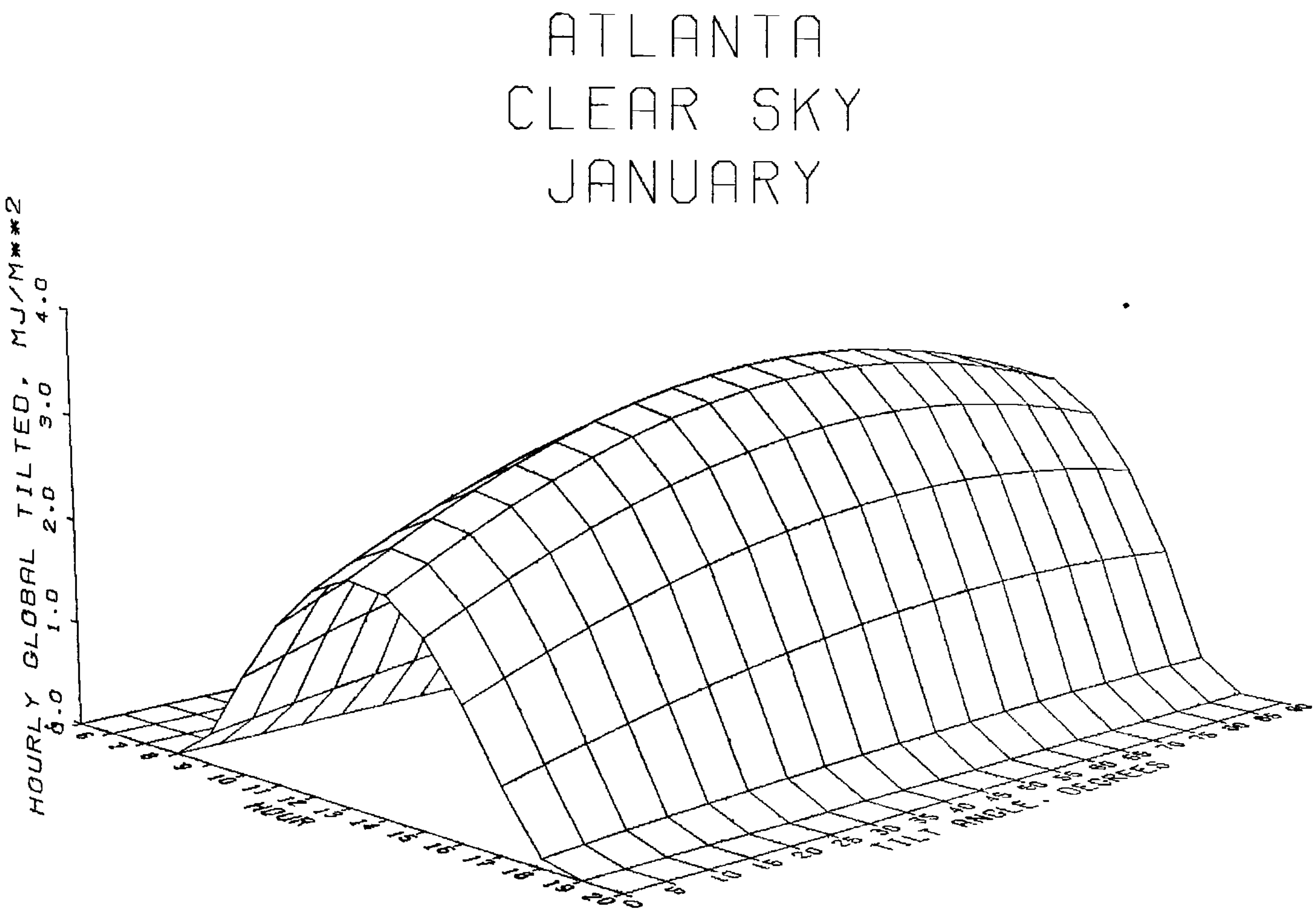

Figure 3.11. Atlanta Clear Sky January Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.12. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.00	.00	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
9	.21	.24	.26	.28	.30	.32	.33	.35	.36	.37	.38	.39	.39	.39	.39	.39	.38	.37	.36
10	.62	.67	.72	.76	.80	.84	.87	.89	.91	.93	.94	.95	.95	.94	.93	.91	.89	.86	.83
11	.95	1.02	1.09	1.14	1.20	1.24	1.28	1.31	1.34	1.35	1.36	1.36	1.35	1.34	1.31	1.28	1.24	1.20	1.15
12	1.18	1.26	1.34	1.40	1.46	1.51	1.55	1.59	1.61	1.63	1.63	1.63	1.62	1.59	1.56	1.52	1.47	1.41	1.35
13	1.28	1.37	1.45	1.52	1.58	1.63	1.68	1.71	1.73	1.75	1.75	1.75	1.73	1.71	1.67	1.63	1.57	1.51	1.44
14	1.25	1.33	1.41	1.48	1.54	1.59	1.64	1.67	1.70	1.71	1.72	1.71	1.70	1.67	1.64	1.59	1.54	1.48	1.41
15	1.09	1.16	1.23	1.30	1.35	1.40	1.44	1.48	1.50	1.52	1.52	1.52	1.51	1.49	1.46	1.43	1.38	1.33	1.27
16	.81	.87	.93	.98	1.03	1.07	1.10	1.13	1.15	1.17	1.18	1.18	1.18	1.17	1.15	1.12	1.09	1.06	1.01
17	.43	.47	.51	.54	.57	.60	.63	.65	.67	.68	.69	.70	.70	.70	.69	.68	.67	.65	.63
18	.07	.08	.09	.09	.10	.11	.11	.12	.13	.13	.13	.14	.14	.14	.14	.14	.14	.14	.13
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

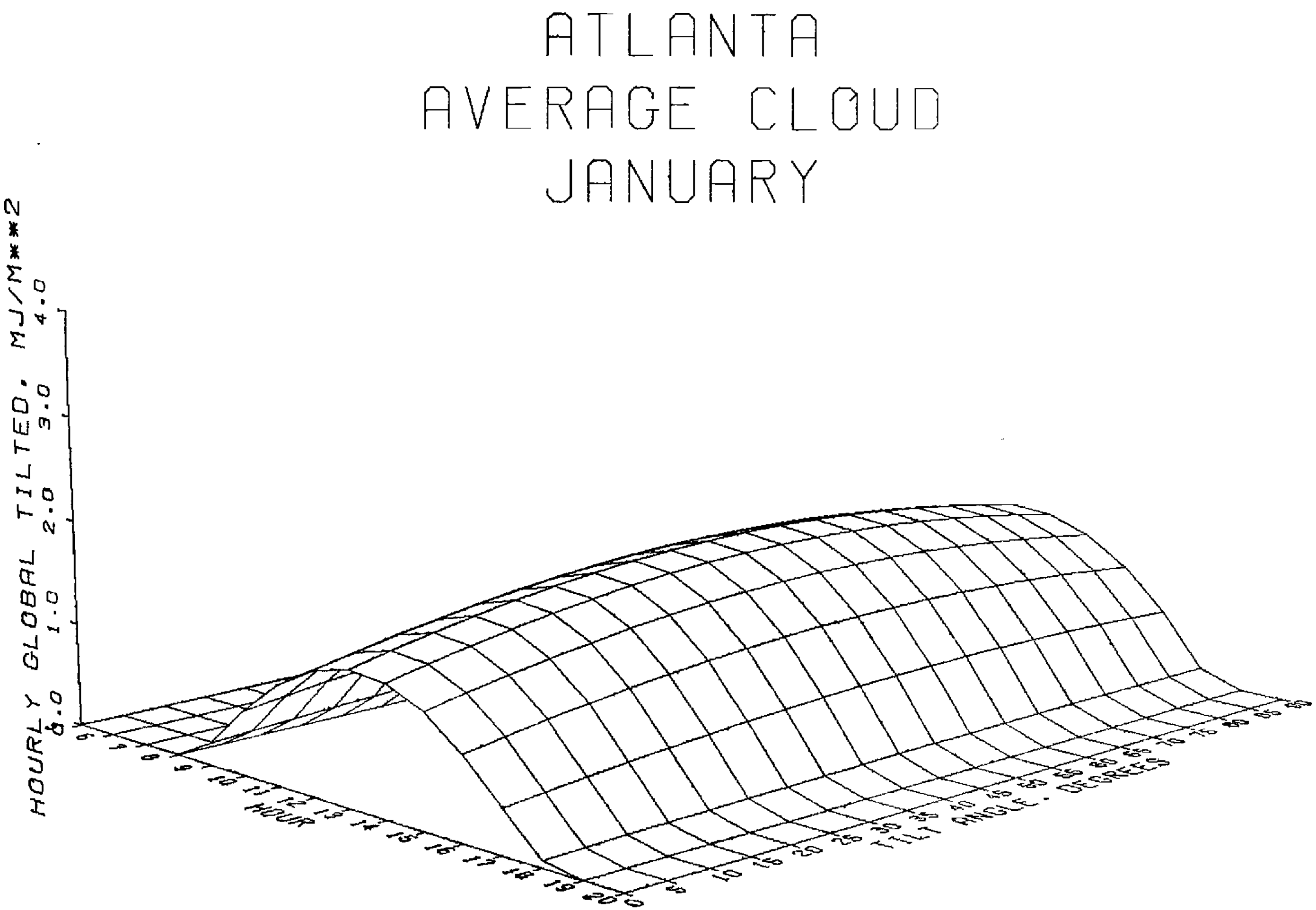

Figure 3.12. Atlanta Average Cloud January Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.13. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

APRIL

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.10	.10	.09	.09	.08	.07	.07	.06	.06	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03
8	.73	.72	.72	.70	.69	.67	.65	.62	.59	.56	.52	.48	.44	.40	.36	.31	.27	.24	.20
9	1.54	1.56	1.57	1.57	1.57	1.55	1.52	1.49	1.45	1.39	1.33	1.27	1.19	1.11	1.02	.93	.83	.73	.63
10	2.29	2.34	2.38	2.40	2.41	2.40	2.38	2.34	2.29	2.22	2.15	2.05	1.95	1.83	1.71	1.57	1.43	1.28	1.12
11	2.89	2.97	3.03	3.07	3.09	3.09	3.07	3.03	2.98	2.90	2.81	2.70	2.57	2.43	2.28	2.11	1.93	1.73	1.53
12	3.29	3.39	3.46	3.51	3.54	3.55	3.53	3.49	3.44	3.35	3.25	3.13	2.99	2.83	2.66	2.46	2.26	2.04	1.81
13	3.45	3.55	3.63	3.68	3.72	3.73	3.71	3.68	3.62	3.53	3.43	3.30	3.16	2.99	2.81	2.61	2.39	2.16	1.92
14	3.35	3.45	3.52	3.58	3.61	3.62	3.60	3.56	3.50	3.42	3.32	3.20	3.05	2.89	2.71	2.52	2.31	2.09	1.85
15	3.01	3.09	3.15	3.20	3.22	3.22	3.21	3.17	3.11	3.03	2.94	2.83	2.70	2.55	2.39	2.21	2.02	1.82	1.61
16	2.45	2.51	2.55	2.58	2.59	2.58	2.56	2.53	2.47	2.40	2.32	2.23	2.12	1.99	1.86	1.71	1.56	1.40	1.23
17	1.73	1.76	1.77	1.78	1.78	1.76	1.74	1.70	1.66	1.60	1.54	1.46	1.38	1.29	1.19	1.09	.98	.87	.75
18	.92	.92	.92	.91	.89	.87	.85	.82	.79	.75	.70	.66	.61	.56	.50	.45	.39	.33	.28
19	.20	.20	.19	.18	.17	.16	.15	.14	.13	.12	.11	.10	.09	.08	.07	.07	.07	.06	.06
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3.13. Atlanta Clear Sky April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.14. **ATLANTA**

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

APRIL

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.08	.08	.08	.07	.07	.07	.06	.06	.06	.05	.05	.05	.04	.04	.04	.04	.04	.04	.03
8	.55	.55	.55	.54	.53	.52	.50	.48	.46	.44	.42	.39	.36	.34	.31	.28	.25	.22	.20
9	1.12	1.13	1.13	1.13	1.13	1.11	1.10	1.07	1.04	1.01	.97	.92	.87	.82	.76	.70	.64	.57	.51
10	1.62	1.65	1.67	1.68	1.68	1.67	1.65	1.63	1.59	1.55	1.49	1.43	1.36	1.29	1.21	1.12	1.03	.93	.83
11	2.02	2.06	2.10	2.11	2.12	2.12	2.10	2.07	2.03	1.98	1.92	1.85	1.76	1.67	1.57	1.46	1.35	1.23	1.10
12	2.28	2.33	2.37	2.40	2.41	2.41	2.39	2.36	2.32	2.27	2.20	2.12	2.03	1.92	1.81	1.69	1.56	1.42	1.28
13	2.38	2.44	2.48	2.51	2.52	2.52	2.51	2.48	2.44	2.38	2.31	2.22	2.13	2.02	1.91	1.78	1.64	1.50	1.35
14	2.32	2.37	2.41	2.44	2.45	2.45	2.44	2.41	2.37	2.31	2.24	2.16	2.07	1.96	1.85	1.72	1.59	1.45	1.30
15	2.10	2.14	2.18	2.20	2.21	2.20	2.19	2.16	2.12	2.06	2.00	1.92	1.84	1.74	1.64	1.53	1.41	1.28	1.15
16	1.73	1.76	1.78	1.80	1.80	1.79	1.77	1.75	1.71	1.66	1.61	1.54	1.47	1.39	1.30	1.21	1.11	1.01	.90
17	1.25	1.26	1.27	1.27	1.27	1.26	1.24	1.21	1.18	1.14	1.10	1.05	1.00	.94	.87	.81	.74	.66	.59
18	.69	.69	.69	.68	.67	.66	.64	.62	.60	.57	.54	.51	.48	.45	.41	.37	.33	.30	.25
19	.16	.16	.16	.15	.14	.14	.13	.12	.12	.11	.10	.10	.09	.08	.08	.07	.07	.07	.06
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

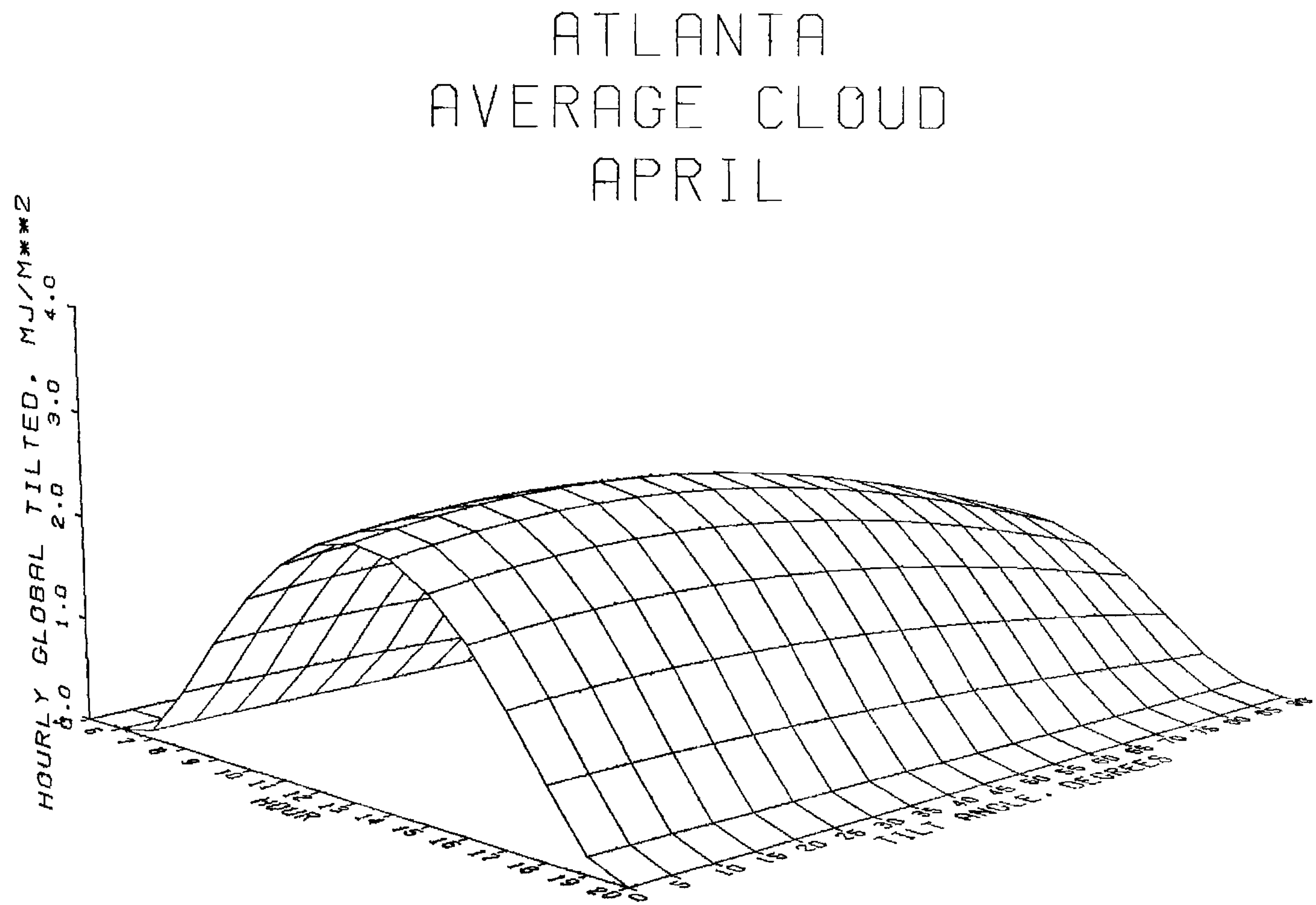

Figure 3.14. Atlanta Average Cloud April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.15. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JULY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.24	.22	.20	.18	.16	.14	.13	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.08	.08
8	.91	.88	.84	.80	.76	.71	.66	.61	.55	.49	.43	.38	.34	.30	.28	.27	.26	.26	.25
9	1.68	1.66	1.63	1.59	1.55	1.49	1.43	1.36	1.28	1.19	1.10	1.01	.91	.80	.69	.59	.49	.43	.41
10	2.40	2.40	2.39	2.36	2.32	2.25	2.19	2.11	2.02	1.92	1.80	1.68	1.55	1.41	1.26	1.11	.96	.80	.64
11	2.98	3.00	3.00	2.99	2.95	2.90	2.83	2.75	2.65	2.53	2.40	2.26	2.10	1.94	1.76	1.57	1.38	1.19	.99
12	3.37	3.41	3.42	3.41	3.39	3.34	3.27	3.18	3.08	2.95	2.81	2.66	2.49	2.30	2.10	1.90	1.68	1.46	1.23
13	3.55	3.59	3.60	3.60	3.58	3.53	3.46	3.37	3.27	3.14	2.99	2.83	2.65	2.46	2.26	2.04	1.81	1.58	1.34
14	3.48	3.52	3.53	3.53	3.50	3.46	3.39	3.30	3.19	3.07	2.93	2.77	2.59	2.40	2.20	1.99	1.76	1.53	1.30
15	3.19	3.21	3.22	3.21	3.18	3.13	3.06	2.97	2.87	2.75	2.61	2.46	2.30	2.12	1.94	1.74	1.54	1.33	1.11
16	2.68	2.69	2.69	2.66	2.63	2.57	2.50	2.42	2.32	2.22	2.09	1.96	1.82	1.66	1.50	1.34	1.16	.99	.80
17	2.02	2.01	1.99	1.95	1.91	1.85	1.79	1.71	1.62	1.53	1.43	1.32	1.20	1.08	.96	.83	.69	.57	.49
18	1.26	1.23	1.20	1.16	1.11	1.06	1.00	.93	.87	.79	.72	.64	.56	.48	.42	.37	.34	.33	.33
19	.51	.48	.45	.42	.39	.35	.31	.28	.25	.23	.20	.19	.18	.18	.17	.17	.16	.16	.16
20	.05	.04	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02

Figure 3.15. Atlanta Clear Sky July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.16. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JULY

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	7	.18	.17	.16	.15	.14	.13	.12	.11	.11	.11	.10	.10	.10	.09	.09	.09	.08	.08	.08
	8	.66	.65	.63	.60	.58	.55	.52	.49	.45	.42	.38	.35	.32	.30	.28	.27	.26	.25	.24
	9	1.18	1.17	1.15	1.13	1.10	1.07	1.03	.99	.94	.89	.83	.77	.71	.65	.58	.52	.46	.41	.39
	10	1.65	1.65	1.64	1.62	1.59	1.56	1.52	1.47	1.41	1.35	1.28	1.20	1.12	1.04	.95	.86	.76	.66	.57
	11	2.02	2.03	2.03	2.01	1.99	1.96	1.92	1.86	1.80	1.73	1.65	1.56	1.47	1.36	1.26	1.14	1.03	.91	.79
HOUR	12	2.27	2.28	2.29	2.28	2.26	2.23	2.18	2.13	2.06	1.99	1.90	1.80	1.70	1.59	1.47	1.34	1.21	1.08	.94
	13	2.37	2.39	2.40	2.40	2.38	2.35	2.30	2.25	2.18	2.10	2.01	1.91	1.80	1.69	1.56	1.43	1.29	1.15	1.01
	14	2.33	2.35	2.36	2.35	2.33	2.30	2.26	2.20	2.14	2.06	1.97	1.87	1.76	1.65	1.53	1.40	1.26	1.13	.98
	15	2.15	2.16	2.16	2.15	2.13	2.10	2.06	2.00	1.94	1.86	1.78	1.69	1.59	1.48	1.37	1.25	1.12	1.00	.87
	16	1.83	1.83	1.83	1.81	1.79	1.75	1.71	1.66	1.60	1.53	1.46	1.38	1.29	1.20	1.10	1.00	.89	.78	.67
	17	1.40	1.39	1.38	1.36	1.33	1.30	1.26	1.21	1.16	1.10	1.04	.97	.90	.83	.75	.67	.59	.51	.46
	18	.90	.88	.86	.84	.81	.78	.75	.71	.67	.63	.58	.53	.48	.44	.39	.36	.34	.32	.31
	19	.38	.37	.35	.33	.32	.29	.27	.25	.24	.22	.21	.19	.19	.18	.18	.17	.16	.16	.15
	20	.04	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02

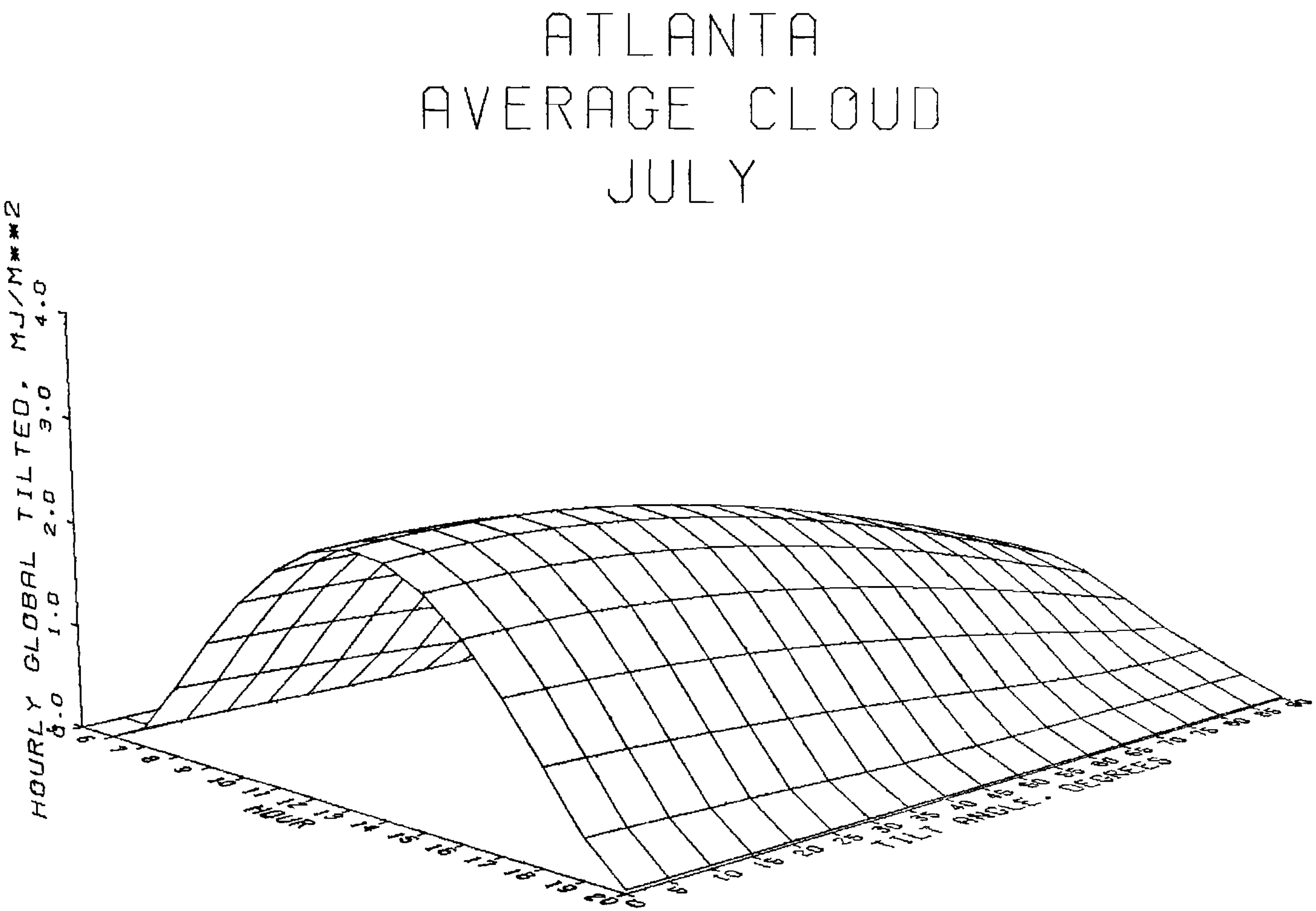

Figure 3.16. Atlanta Average Cloud July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.17. **ATLANTA**

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

OCTOBER

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
	8	.23	.30	.33	.35	.36	.38	.39	.40	.41	.42	.42	.42	.42	.42	.41	.40	.39	.38	.36
	9	.98	1.04	1.11	1.16	1.21	1.25	1.28	1.31	1.33	1.34	1.34	1.33	1.31	1.29	1.26	1.22	1.17	1.11	1.05
	10	1.67	1.78	1.88	1.96	2.03	2.10	2.14	2.18	2.20	2.20	2.19	2.17	2.14	2.09	2.03	1.95	1.87	1.77	1.66
	11	2.22	2.36	2.48	2.59	2.68	2.76	2.81	2.85	2.87	2.87	2.86	2.82	2.77	2.70	2.62	2.51	2.39	2.26	2.11
HOUR	12	2.56	2.72	2.86	2.98	3.08	3.16	3.22	3.27	3.29	3.29	3.26	3.22	3.16	3.08	2.98	2.85	2.72	2.56	2.39
	13	2.66	2.82	2.96	3.09	3.19	3.28	3.34	3.38	3.40	3.40	3.38	3.33	3.27	3.18	3.08	2.95	2.81	2.64	2.47
	14	2.50	2.65	2.79	2.91	3.01	3.09	3.15	3.19	3.21	3.21	3.19	3.15	3.09	3.01	2.91	2.79	2.66	2.51	2.34
	15	2.11	2.24	2.36	2.46	2.55	2.62	2.67	2.71	2.73	2.73	2.72	2.69	2.64	2.57	2.49	2.40	2.28	2.16	2.02
	16	1.51	1.61	1.70	1.78	1.85	1.90	1.95	1.98	2.00	2.01	2.00	1.98	1.95	1.91	1.85	1.79	1.71	1.62	1.52
	17	.80	.86	.91	.96	1.00	1.03	1.06	1.08	1.10	1.11	1.11	1.11	1.10	1.08	1.05	1.02	.98	.94	.89
	18	.16	.17	.18	.20	.21	.22	.22	.23	.24	.24	.24	.25	.24	.24	.24	.24	.23	.22	.21
	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3.17. Atlanta Clear Sky October Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.18. ATLANTA

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

OCTOBER

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
8	.22	.24	.25	.26	.27	.28	.28	.29	.29	.29	.30	.29	.29	.29	.28	.27	.27	.26	.24
9	.74	.77	.81	.84	.86	.88	.90	.91	.92	.92	.91	.91	.89	.87	.85	.82	.79	.75	.71
10	1.22	1.28	1.33	1.38	1.42	1.45	1.47	1.49	1.49	1.49	1.48	1.46	1.43	1.39	1.35	1.30	1.24	1.18	1.10
11	1.59	1.67	1.74	1.80	1.85	1.89	1.91	1.93	1.93	1.93	1.91	1.88	1.84	1.79	1.73	1.66	1.58	1.50	1.40
12	1.82	1.91	1.99	2.05	2.11	2.15	2.18	2.20	2.20	2.19	2.17	2.14	2.09	2.03	1.96	1.88	1.79	1.69	1.58
13	1.89	1.98	2.06	2.12	2.18	2.22	2.25	2.27	2.27	2.27	2.24	2.21	2.16	2.10	2.03	1.94	1.85	1.74	1.63
14	1.78	1.87	1.94	2.01	2.06	2.10	2.13	2.15	2.15	2.14	2.12	2.09	2.05	1.99	1.92	1.84	1.75	1.65	1.55
15	1.52	1.59	1.66	1.71	1.76	1.79	1.82	1.84	1.84	1.84	1.82	1.79	1.76	1.71	1.65	1.59	1.51	1.43	1.34
16	1.11	1.17	1.22	1.26	1.29	1.32	1.34	1.36	1.36	1.36	1.35	1.33	1.31	1.28	1.24	1.19	1.14	1.08	1.02
17	.61	.64	.67	.70	.72	.74	.75	.76	.77	.77	.76	.76	.75	.73	.71	.69	.66	.63	.60
18	.13	.14	.14	.15	.15	.16	.16	.17	.17	.17	.17	.17	.17	.17	.16	.16	.16	.15	.14
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3.18. Atlanta Average Cloud October Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.19. MIAMI

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	1	16.1	17.5	18.8	19.9	21.0	21.8	22.6	23.2	23.7	24.0	24.1	24.1	23.9	23.6	23.1	22.4	21.6	20.7	19.7
	2	19.3	20.5	21.5	22.5	23.3	23.9	24.4	24.7	24.9	24.9	24.8	24.4	24.0	23.4	22.6	21.7	20.7	19.5	18.2
	3	24.0	24.9	25.6	26.1	26.5	26.8	26.8	26.7	26.4	26.0	25.4	24.6	23.7	22.7	21.5	20.1	18.7	17.1	15.5
	4	26.7	27.1	27.2	27.2	27.1	26.7	26.3	25.6	24.8	23.9	22.8	21.6	20.2	18.8	17.3	15.7	14.0	12.2	10.5
	5	28.4	28.4	28.1	27.7	27.1	26.4	25.5	24.4	23.3	22.0	20.6	19.1	17.5	15.8	14.1	12.4	10.7	9.0	7.5
MONTH	6	29.8	29.4	29.0	28.3	27.5	26.5	25.4	24.2	22.8	21.3	19.8	18.1	16.4	14.7	12.9	11.2	9.5	8.0	6.7
	7	29.5	29.3	28.8	28.3	27.5	26.6	25.6	24.4	23.1	21.7	20.2	18.6	16.9	15.2	13.4	11.7	10.0	8.4	7.0
	8	27.9	28.0	27.9	27.7	27.3	26.8	26.1	25.2	24.2	23.1	21.9	20.5	19.0	17.5	15.8	14.2	12.4	10.7	9.0
	9	24.9	25.5	25.9	26.2	26.3	26.2	26.0	25.6	25.1	24.4	23.6	22.7	21.6	20.4	19.1	17.7	16.1	14.6	12.9
	10	21.3	22.3	23.2	23.9	24.5	24.9	25.2	25.3	25.3	25.1	24.8	24.2	23.6	22.8	21.9	20.8	19.6	18.3	16.9
	11	17.4	18.7	19.9	21.0	21.9	22.7	23.4	23.9	24.2	24.4	24.4	24.3	24.0	23.6	23.0	22.2	21.3	20.3	19.2
	12	15.2	16.6	17.9	19.1	20.2	21.2	22.0	22.7	23.2	23.6	23.8	23.8	23.7	23.4	23.0	22.4	21.7	20.9	19.9
ANNUAL MEAN		23.4	24.0	24.5	24.8	25.0	25.0	24.9	24.7	24.2	23.7	23.0	22.2	21.2	20.1	19.0	17.7	16.4	15.0	13.6

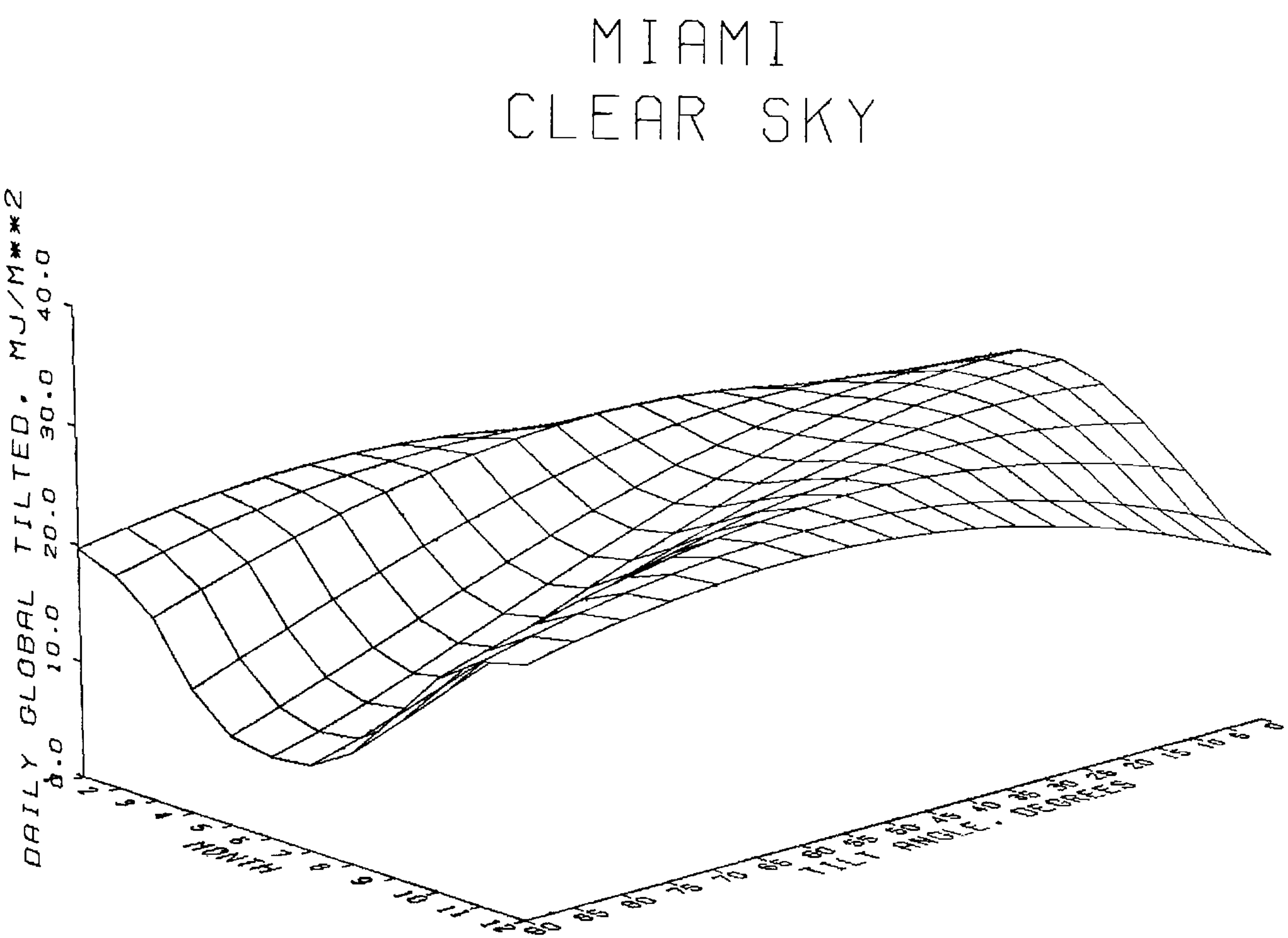

Figure 3.19. Miami Clear Sky Daily Global Tilted Radiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.20. MIAMI

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	1	11.5	12.3	13.0	13.6	14.1	14.6	15.0	15.3	15.5	15.6	15.6	15.5	15.3	15.0	14.7	14.2	13.7	13.1	12.4
	2	14.5	15.2	15.8	16.4	16.9	17.2	17.5	17.7	17.7	17.7	17.5	17.2	16.9	16.4	15.9	15.2	14.5	13.7	12.8
	3	17.5	18.0	18.4	18.7	18.9	19.0	19.0	18.9	18.6	18.3	17.8	17.3	16.7	15.9	15.1	14.2	13.3	12.2	11.1
	4	19.1	19.3	19.4	19.4	19.2	19.0	18.7	18.2	17.7	17.0	16.3	15.5	14.6	13.7	12.7	11.6	10.5	9.4	8.3
	5	19.5	19.5	19.3	19.1	18.7	18.3	17.7	17.1	16.4	15.6	14.7	13.8	12.8	11.8	10.7	9.7	8.6	7.6	6.6
MONTH	6	18.7	18.5	18.3	17.9	17.5	17.0	16.4	15.8	15.1	14.3	13.4	12.5	11.6	10.7	9.7	8.7	7.8	6.9	6.2
	7	18.9	18.8	18.5	18.2	17.8	17.4	16.8	16.1	15.4	14.6	13.8	12.9	12.0	11.0	10.0	9.1	8.1	7.2	6.3
	8	18.7	18.8	18.7	18.6	18.3	18.0	17.5	17.0	16.4	15.7	15.0	14.2	13.3	12.4	11.4	10.4	9.4	8.3	7.3
	9	16.1	16.3	16.5	16.6	16.6	16.5	16.3	16.1	15.7	15.3	14.8	14.3	13.6	12.9	12.2	11.4	10.5	9.6	8.7
	10	14.5	15.0	15.4	15.8	16.0	16.2	16.3	16.3	16.2	16.0	15.7	15.4	14.9	14.4	13.8	13.1	12.4	11.6	10.8
	11	12.4	13.2	13.8	14.4	14.9	15.3	15.6	15.8	15.9	16.0	15.9	15.8	15.5	15.2	14.8	14.3	13.7	13.0	12.3
	12	10.9	11.7	12.4	13.0	13.6	14.1	14.5	14.8	15.1	15.2	15.3	15.2	15.1	14.9	14.6	14.2	13.7	13.1	12.5
	ANNUAL MEAN	16.0	16.4	16.6	16.8	16.9	16.9	16.8	16.6	16.3	15.9	15.5	15.0	14.4	13.7	13.0	12.2	11.3	10.5	9.6

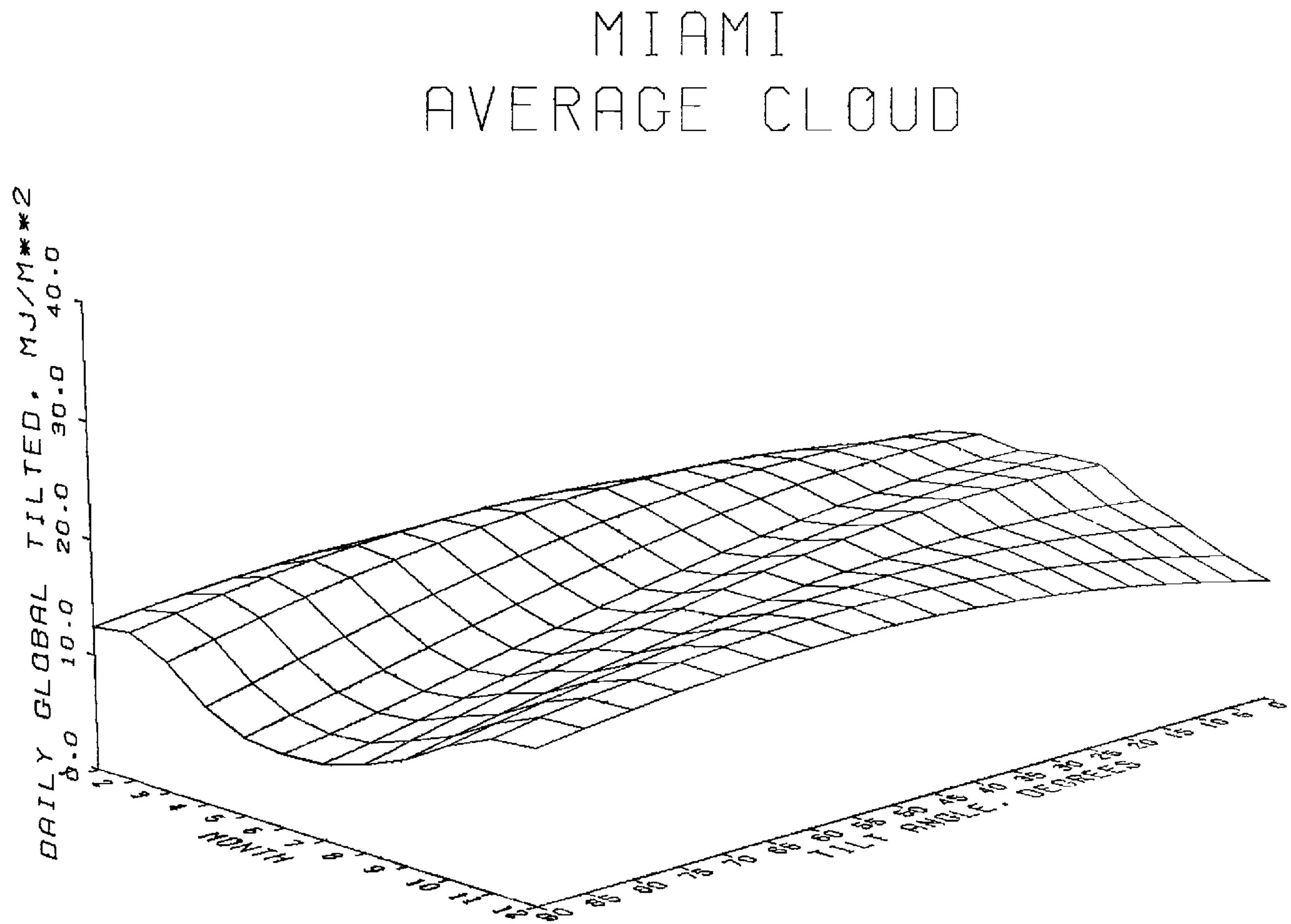

Figure 3.20. Miami Average Cloud Daily Global Tilted Radiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.21. MIAMI

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.004	.008	.002	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.010	.074	.143	.165	.133	.088	.052	.026	.004	0.000
8	.046	.076	.161	.275	.340	.362	.343	.316	.282	.220	.134	.065
9	.204	.251	.317	.431	.492	.515	.505	.498	.476	.392	.292	.205
10	.316	.373	.426	.547	.606	.632	.629	.635	.620	.513	.396	.298
11	.390	.457	.502	.628	.687	.714	.717	.732	.718	.593	.464	.358
12	.433	.507	.548	.675	.733	.762	.770	.790	.773	.634	.499	.391
13	.447	.526	.564	.687	.743	.775	.787	.808	.785	.638	.502	.398
14	.433	.513	.550	.664	.718	.752	.767	.784	.753	.604	.474	.379
15	.389	.468	.506	.606	.657	.694	.710	.720	.678	.532	.413	.334
16	.314	.390	.431	.514	.561	.601	.618	.617	.559	.421	.317	.260
17	.201	.275	.324	.387	.431	.475	.491	.474	.394	.261	.172	.146
18	.043	.107	.172	.216	.261	.310	.325	.284	.171	.054	.015	.015
19	0.000	.001	.014	.029	.059	.102	.112	.060	.005	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	3.22	3.94	4.53	5.73	6.43	6.87	6.91	6.81	6.27	4.89	3.68	2.85

Figure 3.21. Miami Clear Sky Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.22. MIAMI

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

	MONTH											
	1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.004	.008	.002	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.010	.081	.159	.184	.146	.093	.054	.028	.004	0.000
8	.053	.086	.194	.323	.399	.430	.400	.357	.316	.258	.160	.079
9	.264	.304	.404	.522	.591	.626	.605	.579	.554	.483	.374	.279
10	.430	.467	.556	.670	.735	.775	.761	.746	.730	.644	.522	.425
11	.541	.578	.661	.773	.836	.879	.872	.864	.850	.749	.619	.521
HOUR 12	.606	.646	.724	.832	.892	.939	.938	.933	.917	.804	.669	.573
13	.627	.670	.746	.848	.905	.955	.958	.954	.931	.809	.673	.584
14	.605	.653	.726	.819	.873	.926	.933	.926	.893	.765	.633	.554
15	.539	.593	.666	.746	.798	.853	.863	.849	.801	.670	.546	.482
16	.427	.489	.563	.629	.678	.736	.748	.725	.656	.521	.409	.364
17	.260	.336	.414	.466	.514	.574	.588	.549	.452	.311	.209	.191
18	.050	.123	.208	.250	.302	.364	.378	.319	.186	.059	.016	.017
19	0.000	.001	.015	.031	.063	.110	.121	.062	.005	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	4.40	4.95	5.89	6.99	7.75	8.36	8.31	7.96	7.35	6.10	4.83	4.07

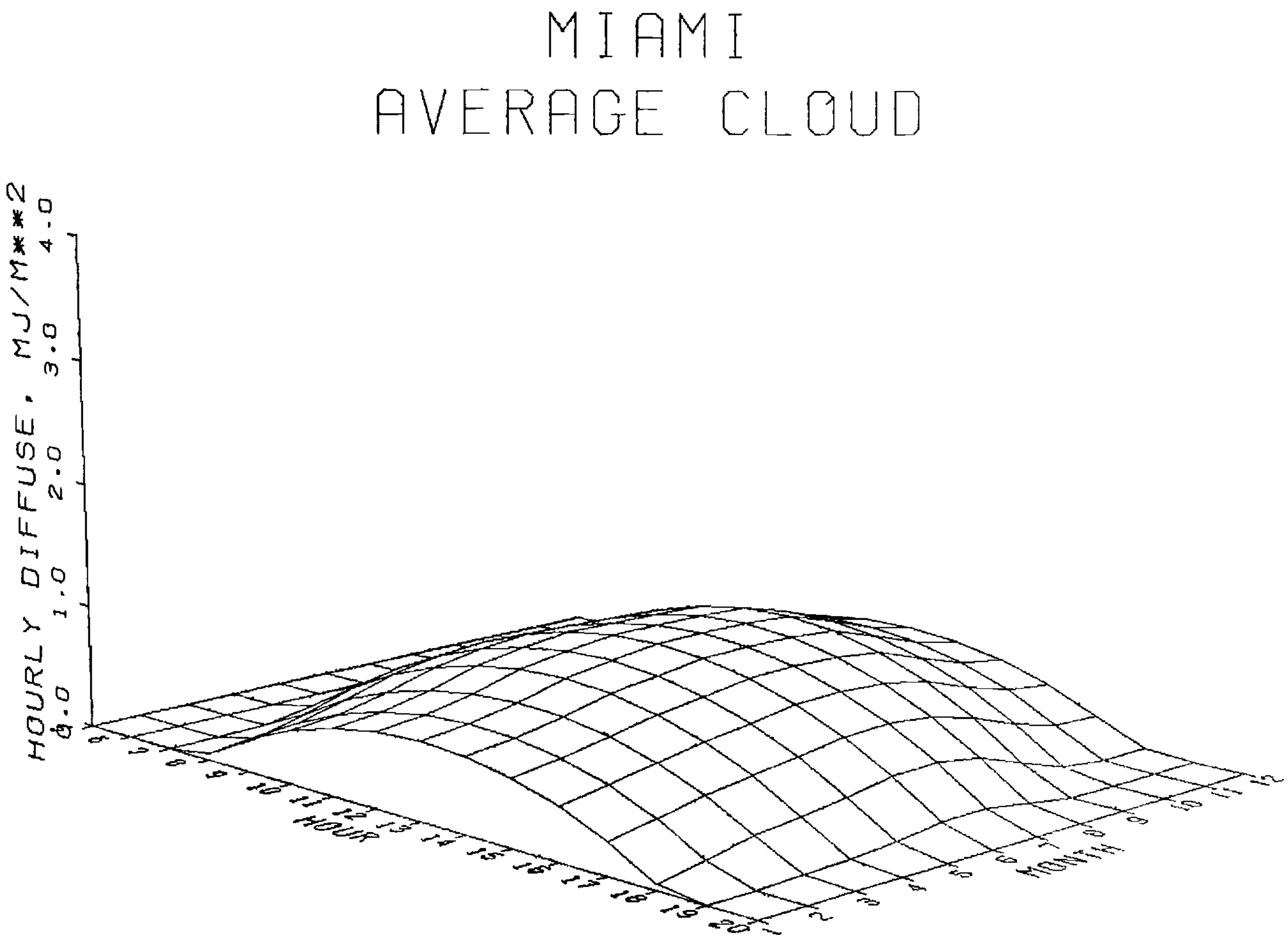

Figure 3.22. Miami Average Cloud Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.23. MIAMI

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

	MONTH											
HOUR	1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.033	.061	.017	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.105	.585	.984	1.089	.882	.570	.346	.218	.042	0.000
8	.506	.724	1.475	1.835	1.968	2.025	1.918	1.733	1.581	1.558	1.232	.775
9	1.939	2.040	2.443	2.461	2.471	2.509	2.449	2.347	2.285	2.371	2.298	2.118
10	2.617	2.641	2.883	2.786	2.746	2.776	2.739	2.672	2.646	2.762	2.769	2.704
11	2.940	2.935	3.106	2.962	2.901	2.926	2.902	2.852	2.838	2.959	2.999	2.985
12	3.091	3.079	3.216	3.049	2.977	3.003	2.985	2.943	2.930	3.047	3.100	3.111
13	3.135	3.126	3.251	3.070	2.993	3.021	3.010	2.969	2.949	3.055	3.109	3.135
14	3.089	3.093	3.220	3.030	2.952	2.987	2.980	2.934	2.898	2.985	3.029	3.067
15	2.935	2.969	3.115	2.919	2.845	2.892	2.890	2.832	2.764	2.814	2.831	2.880
16	2.607	2.708	2.900	2.705	2.647	2.713	2.717	2.635	2.507	2.475	2.425	2.488
17	1.917	2.180	2.478	2.309	2.292	2.398	2.411	2.278	2.020	1.784	1.534	1.620
18	.478	1.001	1.558	1.525	1.626	1.818	1.847	1.599	1.039	.433	.156	.189
19	0.000	.010	.145	.238	.429	.703	.751	.394	.039	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	.003	.005	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	25.25	26.51	29.90	29.47	29.36	30.92	30.50	28.76	26.84	26.46	25.52	25.07

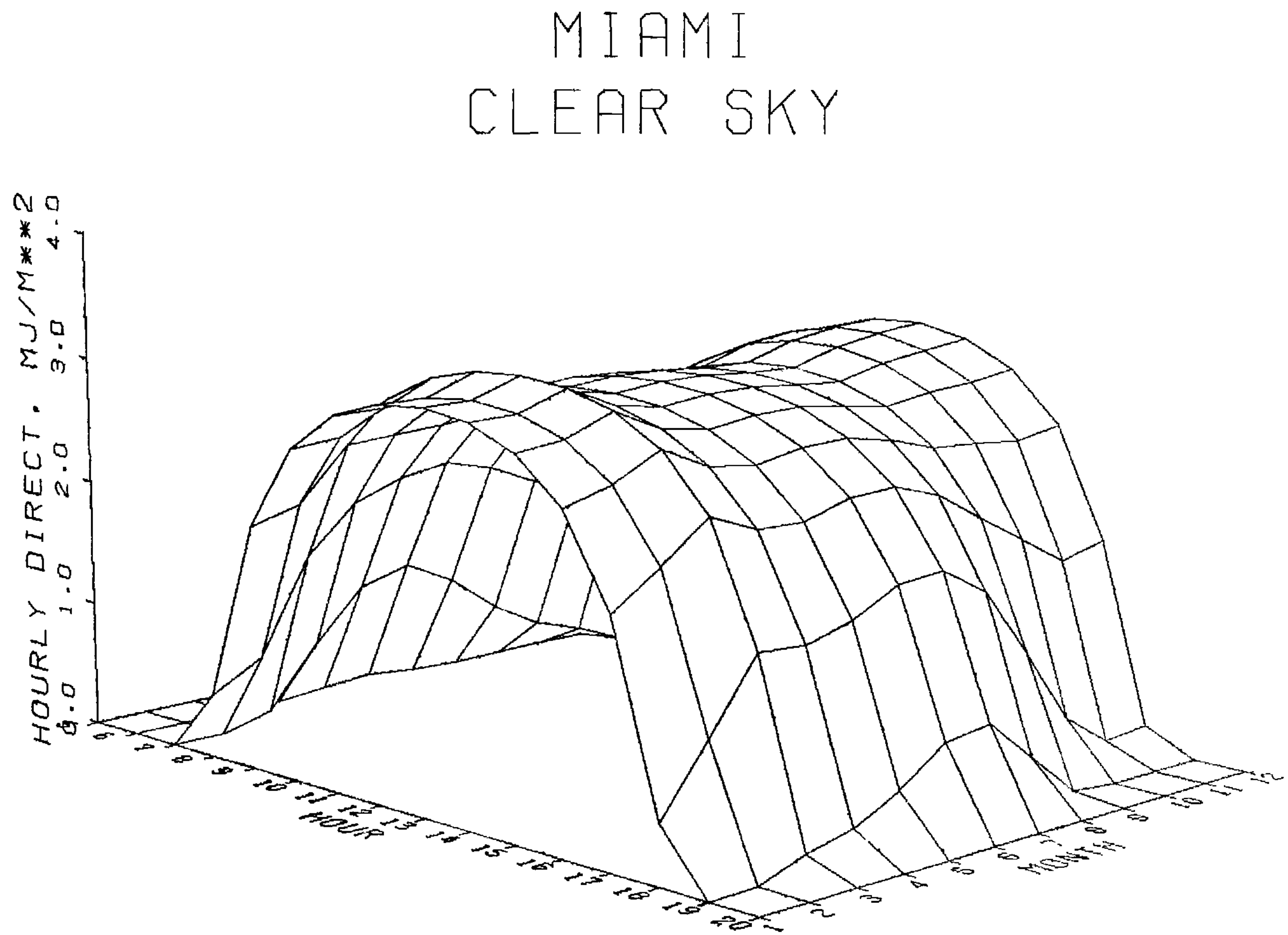

Figure 3.23. Miami Clear Sky Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.24. MIAMI

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

	MONTH											
HOUR	1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.018	.027	.008	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.063	.338	.527	.491	.412	.290	.162	.111	.023	0.000
8	.279	.449	.877	1.061	1.054	.912	.897	.884	.739	.794	.681	.428
9	1.071	1.266	1.453	1.422	1.323	1.130	1.145	1.197	1.068	1.209	1.270	1.170
10	1.446	1.639	1.715	1.610	1.471	1.250	1.280	1.363	1.237	1.408	1.530	1.494
11	1.624	1.821	1.848	1.712	1.553	1.318	1.356	1.455	1.327	1.509	1.657	1.649
12	1.708	1.910	1.914	1.762	1.594	1.353	1.396	1.501	1.370	1.554	1.713	1.719
13	1.732	1.940	1.935	1.775	1.603	1.361	1.407	1.514	1.378	1.558	1.718	1.732
14	1.707	1.919	1.916	1.751	1.581	1.346	1.393	1.496	1.355	1.522	1.673	1.695
15	1.622	1.842	1.853	1.687	1.524	1.303	1.351	1.444	1.292	1.435	1.564	1.591
16	1.440	1.680	1.726	1.564	1.417	1.222	1.270	1.344	1.172	1.262	1.340	1.375
17	1.059	1.353	1.475	1.335	1.227	1.080	1.127	1.162	.944	.910	.847	.895
18	.264	.621	.927	.881	.871	.819	.863	.815	.486	.221	.086	.105
19	0.000	.006	.086	.138	.230	.317	.351	.201	.018	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	.001	.003	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	13.95	16.45	17.79	17.04	15.99	13.93	14.26	14.67	12.55	13.49	14.10	13.85

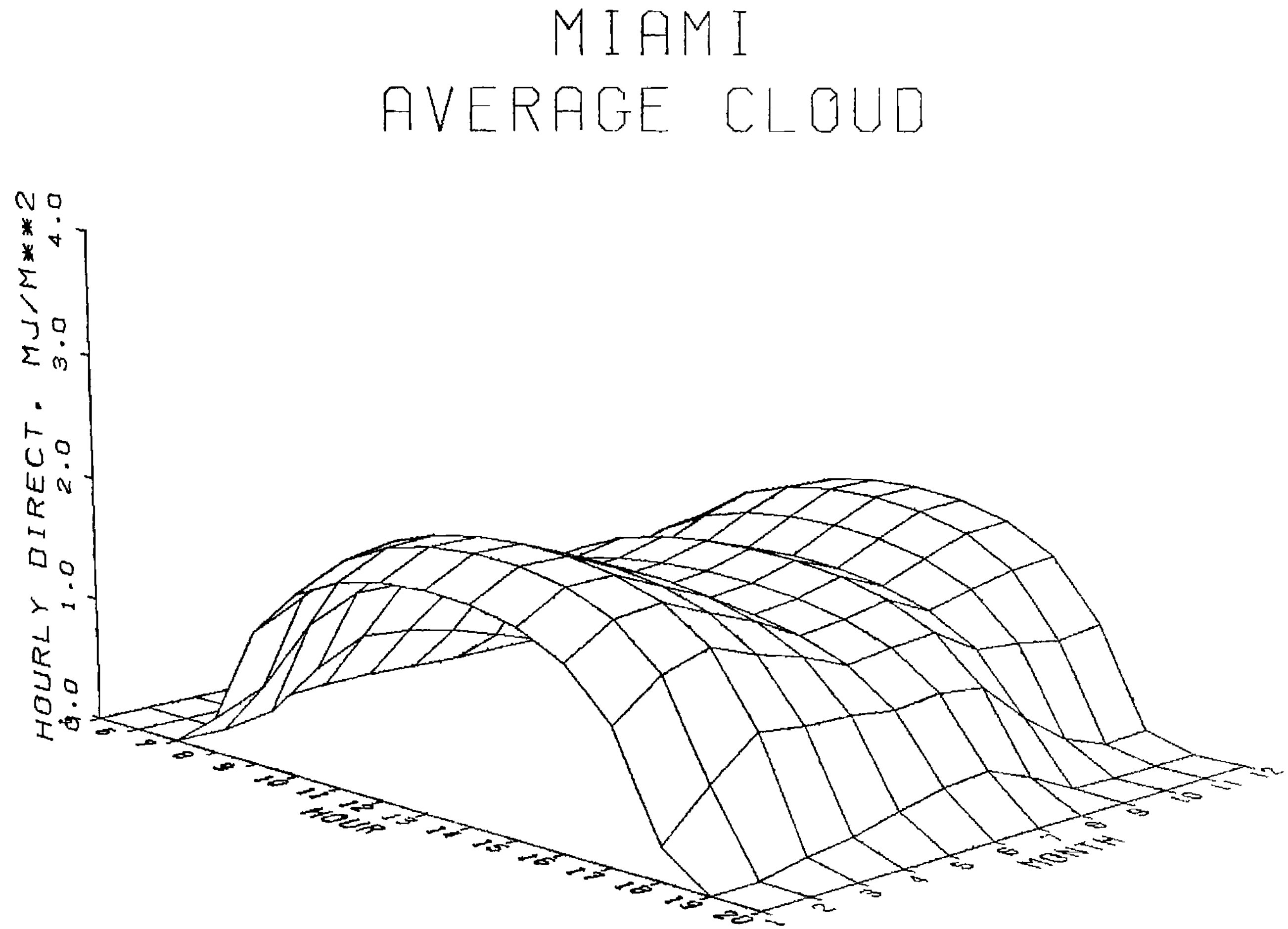

Figure 3.24. Miami Average Cloud Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.25. MIAMI

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

	MONTH											
HOUR	1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	.006	.013	.003	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	.017	.168	.355	.411	.312	.187	.103	.050	.006	0.000
8	.105	.185	.495	.909	1.151	1.215	1.099	.939	.790	.636	.369	.166
9	.728	.913	1.363	1.781	1.994	2.054	1.950	1.815	1.672	1.482	1.136	.820
10	1.459	1.702	2.191	2.565	2.734	2.790	2.708	2.604	2.465	2.241	1.852	1.510
11	2.059	2.348	2.847	3.165	3.295	3.352	3.297	3.215	3.067	2.800	2.386	2.053
12	2.442	2.773	3.269	3.529	3.627	3.693	3.664	3.594	3.421	3.108	2.681	2.375
13	2.572	2.935	3.419	3.625	3.702	3.784	3.782	3.710	3.498	3.137	2.709	2.444
14	2.436	2.820	3.285	3.444	3.514	3.619	3.639	3.553	3.291	2.885	2.468	2.256
15	2.048	2.439	2.878	3.002	3.079	3.210	3.248	3.137	2.817	2.374	1.979	1.827
16	1.444	1.827	2.234	2.337	2.434	2.592	2.641	2.495	2.118	1.651	1.293	1.203
17	.712	1.054	1.414	1.513	1.637	1.817	1.869	1.686	1.266	.809	.518	.489
18	.097	.283	.543	.645	.788	.970	1.016	.809	.411	.113	.028	.028
19	0.000	.001	.025	.056	.122	.227	.252	.119	.008	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	.001	.001	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	16.10	19.28	23.98	26.74	28.44	29.75	29.48	27.86	24.93	21.29	17.43	15.17

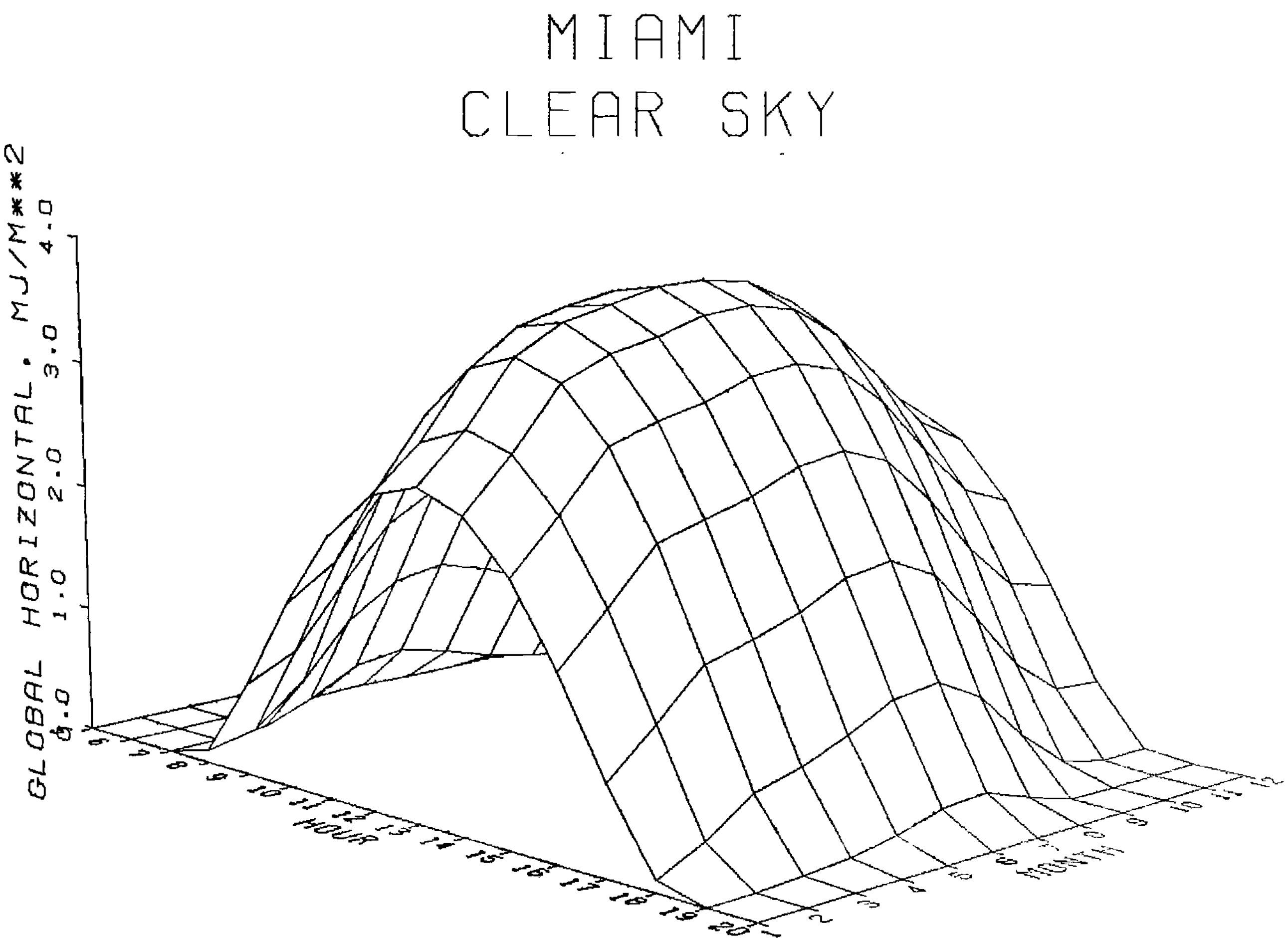

Figure 3.25. Miami Clear Sky Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.26. MIAMI

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.005	.010	.003	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.015	.136	.272	.295	.229	.144	.078	.040	.005	0.000
	8	.086	.153	.393	.693	.834	.814	.754	.675	.554	.470	.290	.135
	9	.554	.715	1.026	1.302	1.395	1.319	1.281	1.251	1.113	1.039	.840	.619
	10	1.061	1.291	1.606	1.836	1.874	1.747	1.734	1.750	1.593	1.525	1.327	1.095
	11	1.463	1.752	2.056	2.240	2.232	2.067	2.078	2.130	1.948	1.875	1.681	1.457
HOUR	12	1.716	2.051	2.343	2.482	2.442	2.259	2.291	2.363	2.155	2.066	1.874	1.669
	13	1.801	2.165	2.444	2.545	2.489	2.310	2.358	2.434	2.199	2.084	1.893	1.715
	14	1.712	2.085	2.354	2.425	2.371	2.218	2.276	2.338	2.079	1.928	1.735	1.591
	15	1.456	1.816	2.077	2.131	2.095	1.987	2.050	2.082	1.801	1.609	1.412	1.307
	16	1.051	1.381	1.636	1.683	1.681	1.633	1.694	1.682	1.385	1.149	.949	.886
	17	.542	.820	1.062	1.117	1.160	1.179	1.232	1.168	.860	.590	.400	.380
	18	.080	.232	.428	.498	.584	.661	.701	.587	.298	.089	.023	.024
	19	0.000	.001	.022	.046	.097	.167	.187	.093	.007	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000
	DAILY TOTAL	11.52	14.46	17.46	19.13	19.53	18.67	18.87	18.70	16.07	14.46	12.43	10.88

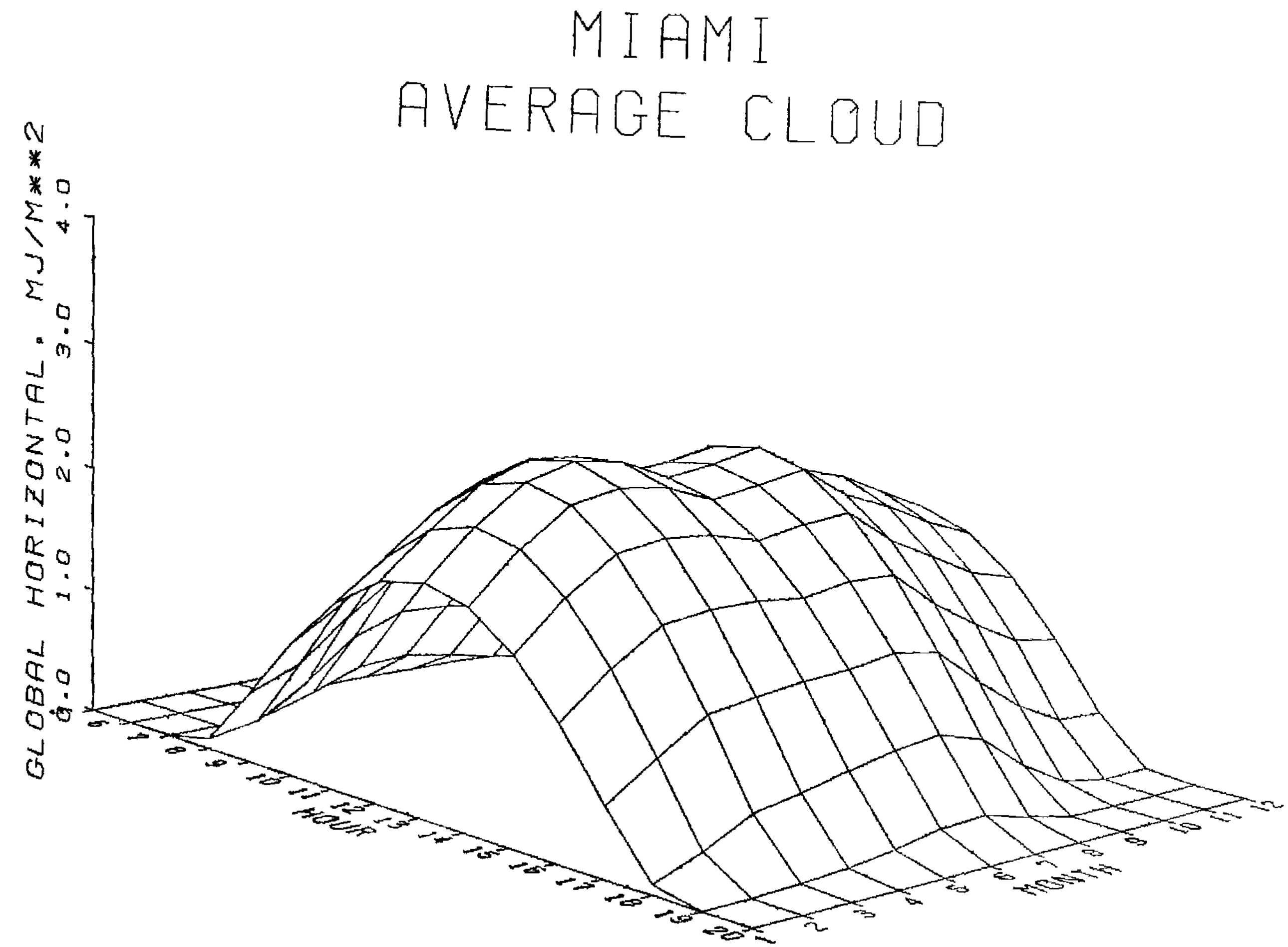

Figure 3.26. Miami Average Cloud Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.27. MIAMI

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.004	.007	.002	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.020	.128	.222	.230	.176	.127	.096	.066	.012	0.000
	8	.198	.275	.555	.817	.918	.905	.822	.783	.787	.783	.576	.322
	9	1.117	1.205	1.514	1.711	1.752	1.719	1.646	1.652	1.716	1.755	1.565	1.280
	10	2.030	2.129	2.425	2.537	2.513	2.467	2.416	2.467	2.564	2.606	2.416	2.144
	11	2.741	2.867	3.147	3.177	3.099	3.050	3.026	3.108	3.211	3.228	3.034	2.790
HOUR	12	3.187	3.347	3.610	3.566	3.448	3.406	3.412	3.509	3.593	3.570	3.371	3.166
	13	3.336	3.529	3.774	3.668	3.528	3.501	3.535	3.632	3.675	3.602	3.402	3.247
	14	3.180	3.400	3.627	3.475	3.330	3.328	3.385	3.466	3.452	3.323	3.127	3.028
	15	2.729	2.971	3.181	3.002	2.873	2.902	2.976	3.026	2.942	2.755	2.564	2.523
	16	2.012	2.274	2.473	2.296	2.202	2.264	2.347	2.353	2.192	1.945	1.755	1.768
	17	1.096	1.374	1.570	1.433	1.393	1.484	1.566	1.521	1.286	.985	.781	.827
	18	.185	.411	.607	.559	.581	.680	.746	.660	.400	.148	.052	.065
	19	0.000	.002	.029	.039	.067	.116	.138	.077	.007	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		21.81	23.78	26.53	26.41	25.93	26.06	26.19	26.38	25.92	24.77	22.66	21.16

MIAMI
CLEAR SKY

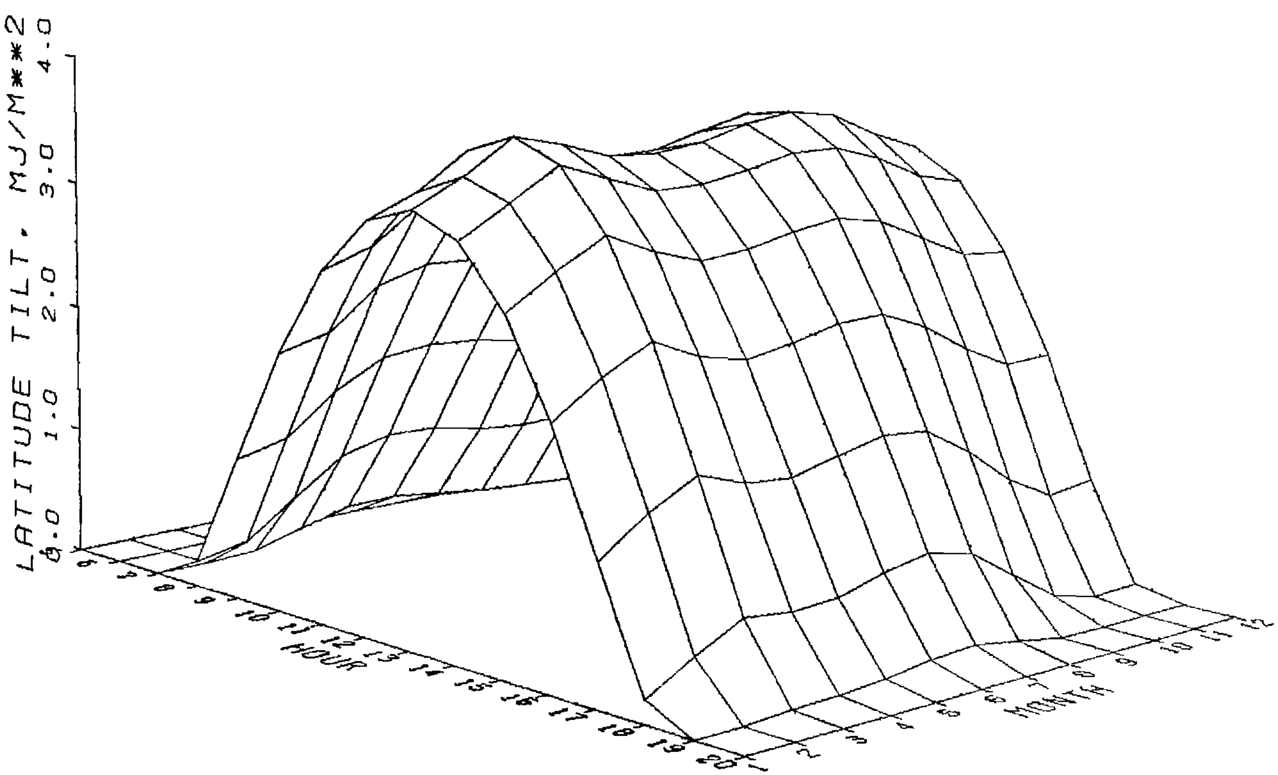

Figure 3.27. Miami Clear Sky Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.28. MIAMI

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	.004	.007	.002	0.000	0.000	0.000	0.000	0.000
	7	0.000	0.000	.016	.111	.197	.208	.162	.111	.073	.048	.009	0.000
	8	.136	.207	.423	.629	.698	.661	.612	.586	.543	.538	.400	.219
	9	.761	.888	1.105	1.248	1.249	1.149	1.120	1.152	1.117	1.164	1.067	.865
	10	1.364	1.545	1.730	1.803	1.736	1.577	1.574	1.659	1.617	1.692	1.623	1.432
	11	1.824	2.059	2.216	2.226	2.104	1.903	1.925	2.051	1.990	2.071	2.021	1.848
HOUR	12	2.109	2.391	2.526	2.481	2.321	2.100	2.144	2.294	2.207	2.277	2.236	2.088
	13	2.204	2.517	2.635	2.548	2.371	2.153	2.213	2.368	2.254	2.297	2.256	2.140
	14	2.105	2.428	2.538	2.422	2.248	2.057	2.129	2.268	2.127	2.128	2.080	2.000
	15	1.816	2.131	2.239	2.111	1.962	1.821	1.896	2.001	1.836	1.783	1.719	1.677
	16	1.352	1.646	1.762	1.642	1.538	1.462	1.534	1.590	1.400	1.283	1.192	1.187
	17	.747	1.010	1.144	1.058	1.015	1.011	1.072	1.068	.856	.671	.540	.562
	18	.127	.309	.462	.442	.465	.519	.563	.502	.288	.105	.036	.044
	19	0.000	.002	.023	.036	.065	.114	.130	.070	.006	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000
	DAILY TOTAL	14.55	17.13	18.82	18.76	17.97	16.74	17.08	17.72	16.31	16.06	15.18	14.06

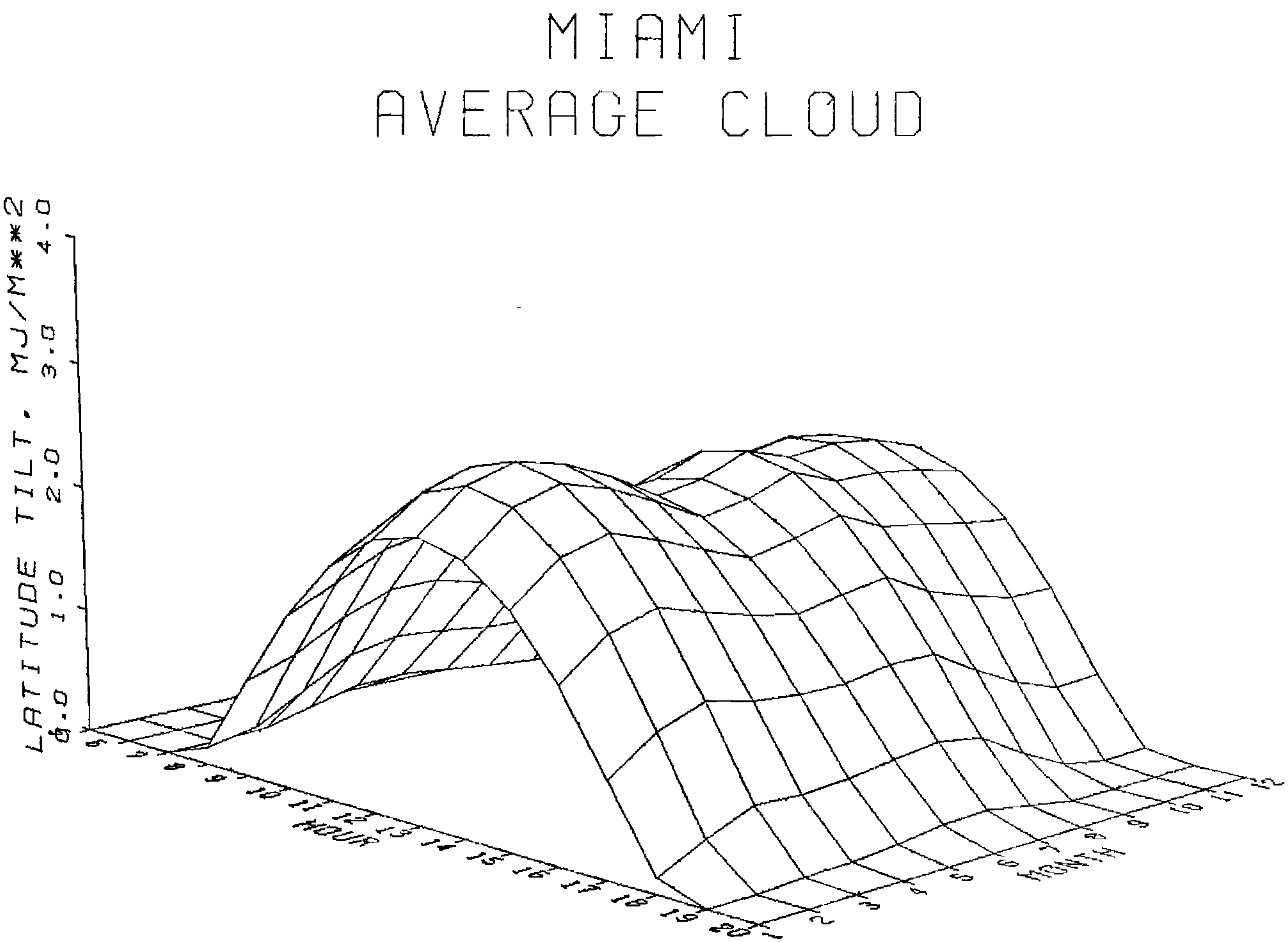

Figure 3.28. Miami Average Cloud Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.29. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.11	.13	.14	.16	.18	.20	.21	.23	.24	.25	.26	.27	.27	.28	.28	.28	.28	.27	.27
9	.73	.82	.90	.98	1.05	1.12	1.17	1.22	1.27	1.30	1.33	1.34	1.35	1.35	1.34	1.32	1.29	1.26	1.21
10	1.46	1.60	1.72	1.84	1.94	2.03	2.11	2.17	2.22	2.26	2.28	2.29	2.28	2.25	2.21	2.16	2.09	2.01	1.91
11	2.06	2.23	2.38	2.52	2.64	2.75	2.83	2.90	2.95	2.98	3.00	2.99	2.96	2.91	2.84	2.76	2.65	2.53	2.40
12	2.44	2.63	2.80	2.95	3.08	3.20	3.29	3.36	3.41	3.43	3.44	3.42	3.37	3.31	3.23	3.12	2.99	2.85	2.68
13	2.57	2.76	2.94	3.09	3.23	3.35	3.44	3.51	3.56	3.58	3.58	3.56	3.51	3.44	3.35	3.24	3.10	2.95	2.78
14	2.44	2.62	2.79	2.94	3.08	3.19	3.28	3.35	3.40	3.43	3.43	3.41	3.37	3.31	3.22	3.11	2.99	2.84	2.68
15	2.05	2.22	2.37	2.51	2.63	2.73	2.82	2.89	2.94	2.97	2.98	2.97	2.95	2.90	2.83	2.75	2.64	2.52	2.39
16	1.44	1.58	1.71	1.82	1.92	2.01	2.09	2.16	2.21	2.24	2.26	2.27	2.26	2.24	2.20	2.14	2.08	2.00	1.90
17	.71	.80	.88	.96	1.03	1.09	1.15	1.20	1.24	1.28	1.30	1.32	1.33	1.33	1.32	1.30	1.27	1.24	1.19
18	.10	.12	.13	.15	.17	.18	.20	.21	.22	.23	.24	.25	.25	.26	.26	.26	.26	.26	.25
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

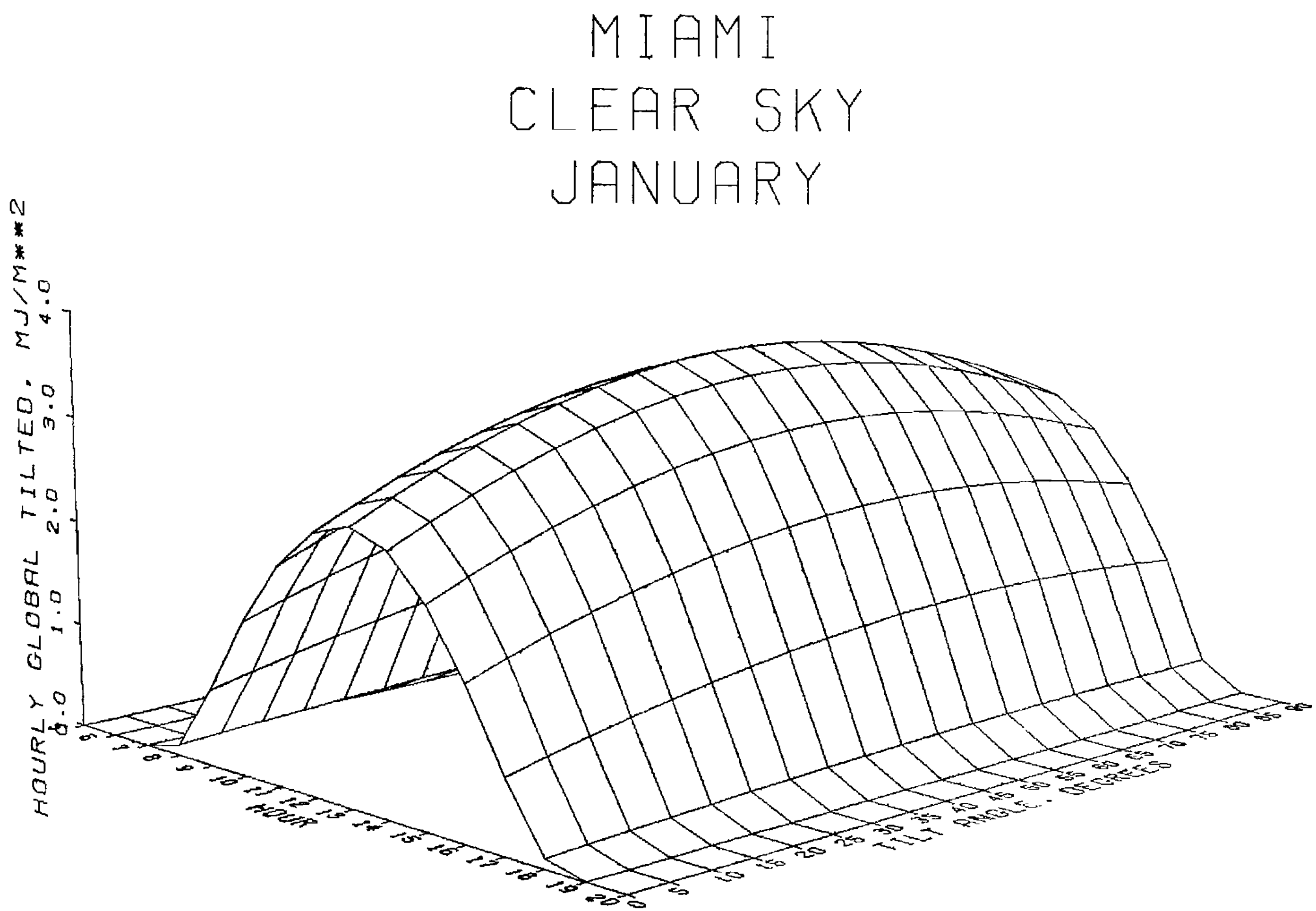

Figure 3.29. Miami Clear Sky January Hourly Global Tilted (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.30. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.09	.10	.11	.12	.13	.14	.14	.15	.16	.16	.17	.17	.17	.17	.17	.17	.17	.17	.16
9	.55	.60	.65	.69	.73	.76	.79	.82	.84	.85	.86	.87	.87	.86	.85	.84	.82	.79	.76
10	1.06	1.14	1.20	1.27	1.32	1.37	1.41	1.44	1.46	1.47	1.48	1.47	1.46	1.44	1.41	1.37	1.33	1.27	1.21
11	1.46	1.56	1.64	1.71	1.78	1.83	1.87	1.91	1.93	1.94	1.93	1.92	1.90	1.86	1.81	1.75	1.68	1.61	1.52
12	1.72	1.82	1.91	1.99	2.06	2.12	2.16	2.20	2.21	2.22	2.21	2.19	2.16	2.11	2.05	1.98	1.90	1.81	1.70
13	1.80	1.91	2.00	2.08	2.16	2.21	2.26	2.29	2.31	2.31	2.31	2.28	2.25	2.20	2.13	2.06	1.97	1.87	1.76
14	1.71	1.81	1.91	1.99	2.06	2.11	2.16	2.19	2.21	2.22	2.21	2.19	2.15	2.11	2.05	1.98	1.90	1.80	1.70
15	1.46	1.55	1.63	1.71	1.77	1.82	1.87	1.90	1.92	1.93	1.93	1.91	1.89	1.85	1.80	1.75	1.68	1.60	1.51
16	1.05	1.13	1.19	1.26	1.31	1.36	1.40	1.43	1.45	1.46	1.47	1.46	1.45	1.43	1.40	1.36	1.32	1.26	1.20
17	.54	.59	.64	.68	.71	.75	.78	.80	.82	.84	.85	.85	.85	.85	.84	.82	.80	.78	.75
18	.08	.09	.10	.11	.12	.13	.13	.14	.15	.15	.16	.16	.16	.16	.16	.16	.16	.16	.15
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

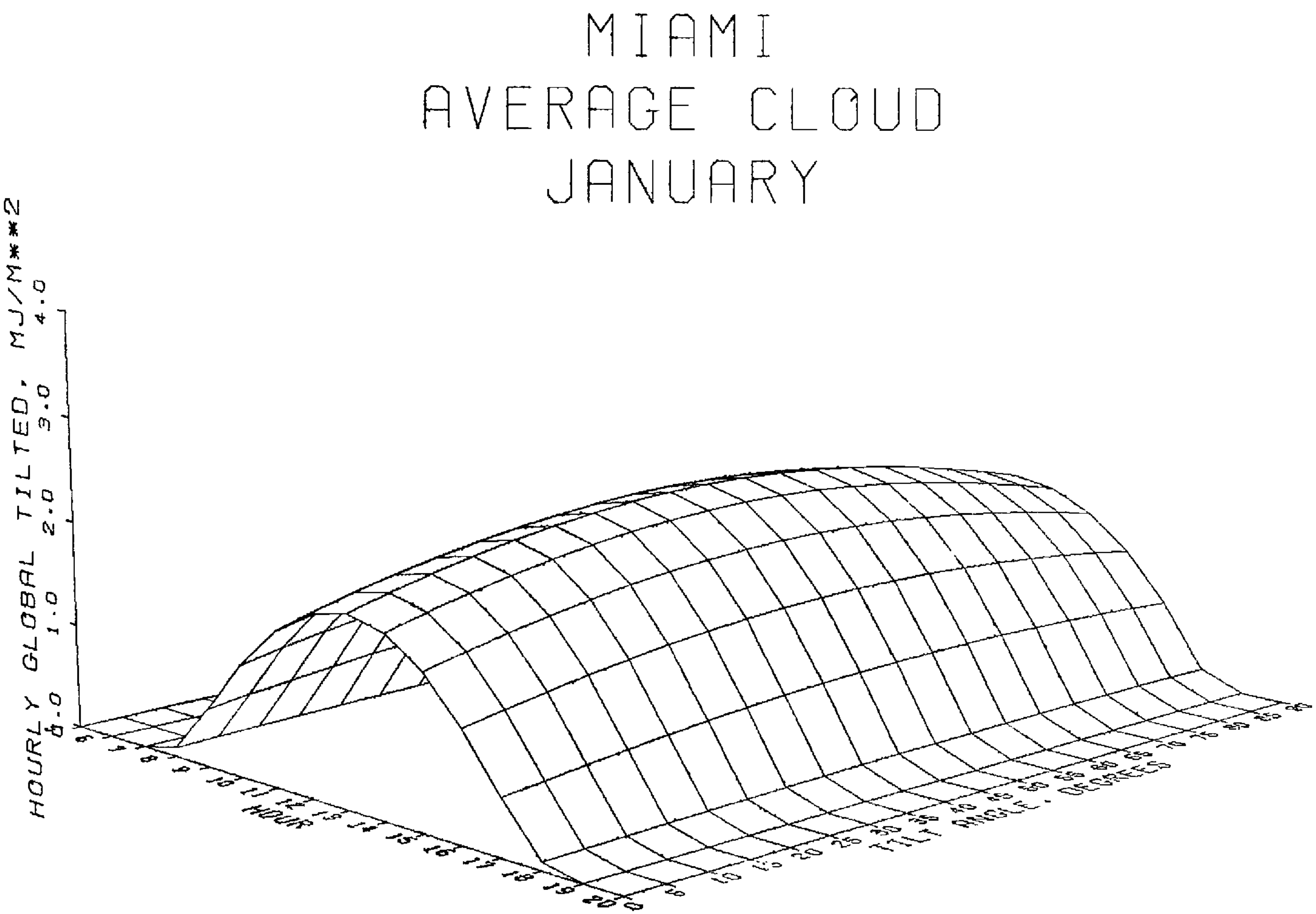

Figure 3.30. Miami Average Cloud January Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.31. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

APRIL

HOUR	TILT ANGLE (DEGREES) 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.17	.16	.16	.15	.14	.13	.12	.11	.10	.10	.09	.08	.07	.07	.06	.06	.06	.06	.05
8	.91	.90	.89	.88	.86	.83	.80	.77	.73	.69	.64	.59	.54	.49	.43	.37	.32	.27	.24
9	1.78	1.79	1.80	1.79	1.77	1.74	1.69	1.64	1.58	1.52	1.44	1.35	1.26	1.16	1.05	.94	.83	.71	.59
10	2.57	2.60	2.61	2.61	2.60	2.57	2.52	2.46	2.38	2.29	2.19	2.07	1.95	1.81	1.66	1.50	1.34	1.17	.99
11	3.17	3.22	3.25	3.26	3.25	3.22	3.17	3.10	3.01	2.90	2.78	2.64	2.49	2.32	2.14	1.94	1.74	1.53	1.31
12	3.53	3.59	3.63	3.64	3.64	3.61	3.56	3.48	3.39	3.28	3.14	2.99	2.82	2.63	2.43	2.21	1.99	1.75	1.51
13	3.63	3.69	3.73	3.75	3.74	3.71	3.66	3.59	3.49	3.37	3.24	3.08	2.90	2.71	2.51	2.29	2.05	1.81	1.56
14	3.44	3.50	3.54	3.55	3.55	3.52	3.47	3.39	3.30	3.19	3.06	2.91	2.74	2.56	2.36	2.15	1.93	1.70	1.46
15	3.00	3.05	3.07	3.08	3.07	3.04	2.99	2.92	2.84	2.74	2.62	2.49	2.34	2.18	2.01	1.82	1.63	1.43	1.22
16	2.34	2.36	2.38	2.37	2.36	2.33	2.28	2.22	2.15	2.07	1.97	1.86	1.74	1.62	1.48	1.34	1.19	1.03	.87
17	1.51	1.52	1.52	1.50	1.48	1.45	1.42	1.37	1.32	1.25	1.19	1.11	1.03	.95	.86	.76	.66	.56	.46
18	.65	.64	.63	.61	.59	.57	.55	.52	.49	.45	.42	.38	.35	.31	.27	.24	.21	.19	.17
19	.06	.05	.05	.05	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

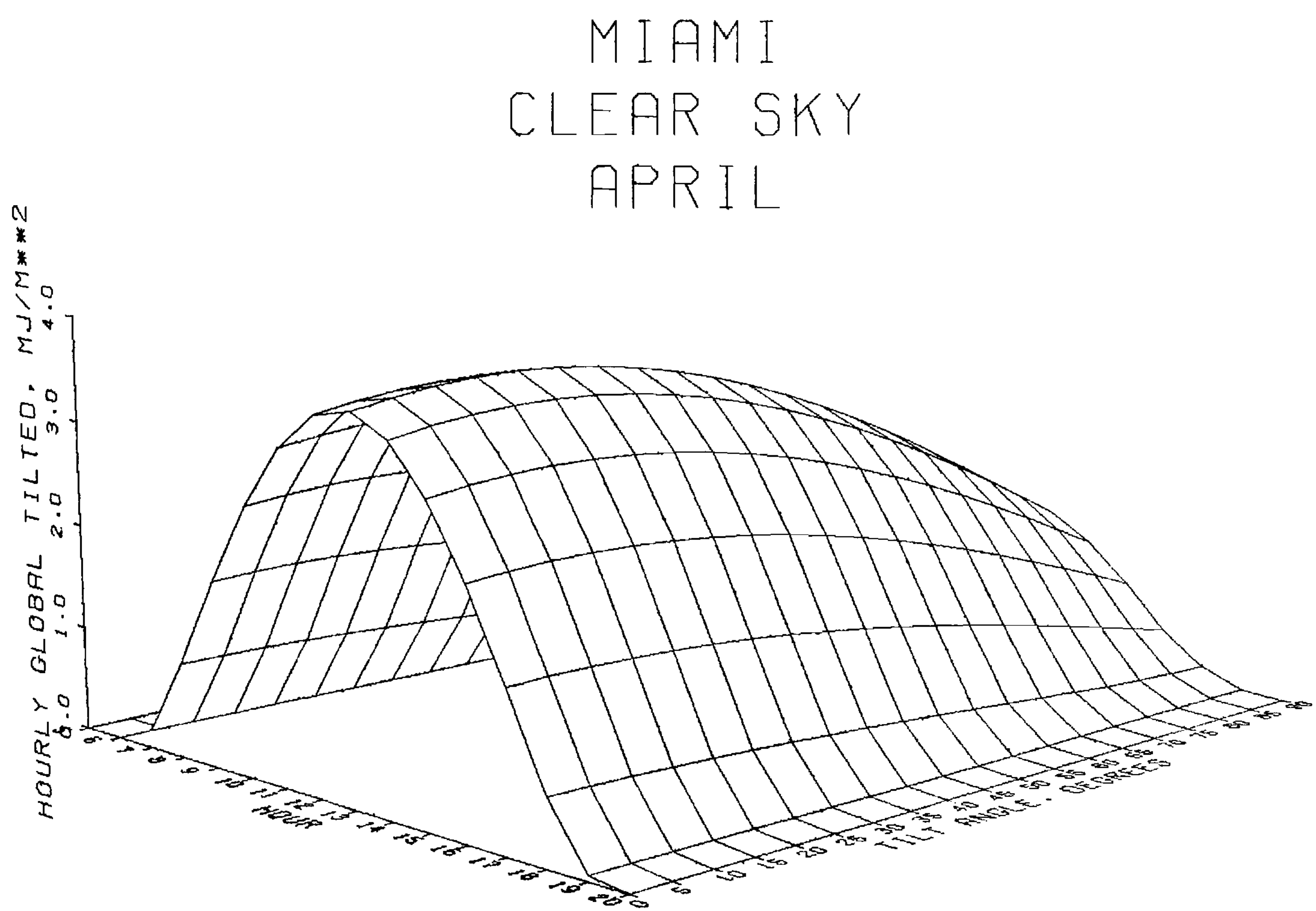

Figure 3.31. Miami Clear Sky April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.32. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

APRIL

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	.14	.13	.13	.12	.12	.11	.11	.10	.10	.09	.08	.08	.07	.07	.06	.06	.06	.06	.05
	8	.69	.69	.68	.67	.66	.64	.62	.60	.57	.54	.51	.48	.44	.41	.37	.33	.30	.26	.24
	9	1.30	1.31	1.31	1.30	1.29	1.27	1.24	1.20	1.16	1.12	1.06	1.01	.95	.88	.81	.74	.66	.58	.51
	10	1.84	1.86	1.86	1.86	1.85	1.83	1.79	1.75	1.70	1.64	1.57	1.49	1.41	1.32	1.22	1.12	1.01	.90	.79
	11	2.24	2.27	2.28	2.29	2.28	2.25	2.22	2.17	2.11	2.04	1.96	1.87	1.77	1.66	1.54	1.41	1.28	1.14	1.00
HOUR	12	2.48	2.52	2.54	2.54	2.53	2.51	2.47	2.42	2.36	2.28	2.19	2.09	1.98	1.86	1.73	1.59	1.44	1.29	1.14
	13	2.55	2.58	2.60	2.61	2.60	2.58	2.54	2.49	2.43	2.35	2.26	2.15	2.04	1.91	1.78	1.64	1.49	1.33	1.17
	14	2.43	2.46	2.48	2.48	2.47	2.45	2.41	2.36	2.30	2.23	2.14	2.04	1.93	1.81	1.68	1.55	1.41	1.26	1.11
	15	2.13	2.16	2.17	2.17	2.16	2.14	2.10	2.06	2.00	1.93	1.85	1.77	1.67	1.56	1.45	1.33	1.21	1.08	.94
	16	1.68	1.70	1.70	1.70	1.69	1.66	1.63	1.59	1.54	1.49	1.42	1.35	1.27	1.19	1.10	1.01	.91	.81	.70
	17	1.12	1.12	1.12	1.11	1.09	1.07	1.05	1.02	.98	.94	.89	.84	.79	.73	.67	.61	.55	.48	.41
	18	.50	.49	.49	.48	.46	.45	.43	.42	.40	.37	.35	.33	.30	.27	.25	.23	.20	.19	.18
	19	.05	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

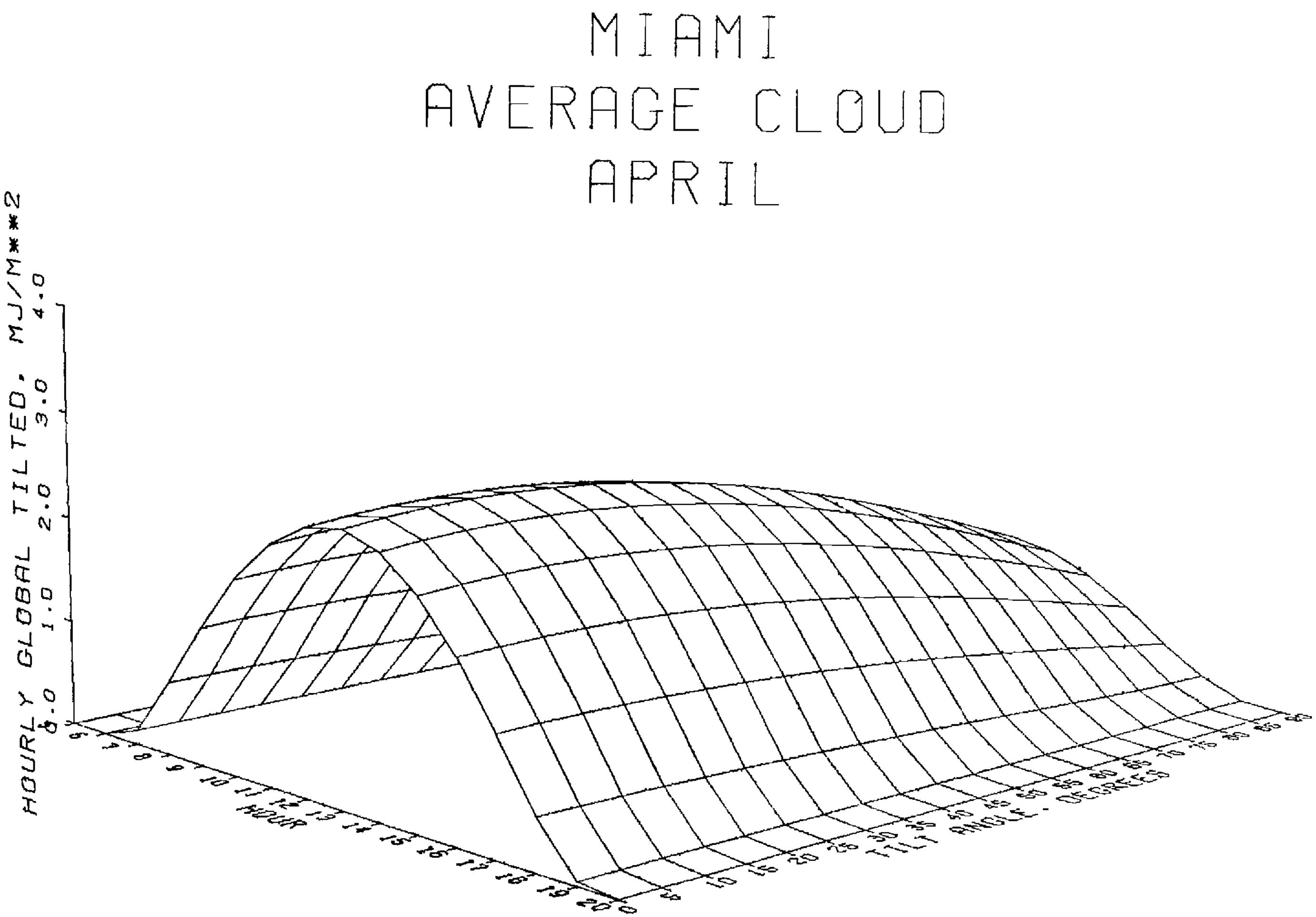

Figure 3.32. Miami Average Cloud April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.33. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JULY

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	7	.31	.29	.26	.23	.21	.18	.16	.14	.13	.12	.12	.12	.12	.11	.11	.11	.10	.10	.10
	8	1.10	1.06	1.01	.96	.90	.84	.78	.71	.64	.56	.49	.42	.36	.32	.30	.30	.29	.29	.28
	9	1.95	1.92	1.87	1.82	1.75	1.68	1.59	1.50	1.40	1.29	1.18	1.06	.93	.80	.67	.55	.47	.45	.45
	10	2.71	2.69	2.66	2.60	2.54	2.46	2.36	2.25	2.13	2.00	1.86	1.70	1.54	1.37	1.20	1.02	.83	.66	.59
	11	3.30	3.29	3.27	3.22	3.16	3.07	2.97	2.86	2.72	2.57	2.41	2.23	2.04	1.84	1.63	1.41	1.19	.97	.74
HOUR	12	3.66	3.67	3.65	3.61	3.55	3.46	3.36	3.24	3.09	2.93	2.75	2.56	2.36	2.14	1.91	1.67	1.43	1.18	.92
	13	3.78	3.79	3.77	3.73	3.67	3.59	3.48	3.36	3.21	3.05	2.87	2.67	2.46	2.23	2.00	1.75	1.50	1.24	.93
	14	3.64	3.64	3.62	3.58	3.52	3.44	3.33	3.21	3.07	2.91	2.73	2.54	2.33	2.12	1.89	1.65	1.41	1.16	.91
	15	3.25	3.24	3.22	3.17	3.11	3.02	2.92	2.81	2.67	2.52	2.36	2.18	2.00	1.80	1.59	1.38	1.16	.94	.72
	16	2.64	2.62	2.59	2.53	2.47	2.39	2.29	2.19	2.07	1.94	1.79	1.64	1.49	1.32	1.15	.97	.79	.63	.57
	17	1.87	1.84	1.79	1.74	1.67	1.60	1.51	1.42	1.32	1.22	1.11	.99	.87	.74	.62	.51	.45	.44	.43
	18	1.02	.98	.93	.88	.83	.77	.70	.64	.57	.50	.43	.37	.33	.30	.29	.28	.27	.27	.26
	19	.25	.23	.21	.19	.16	.14	.13	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.08	.08
	20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0.00	0.00	0.00

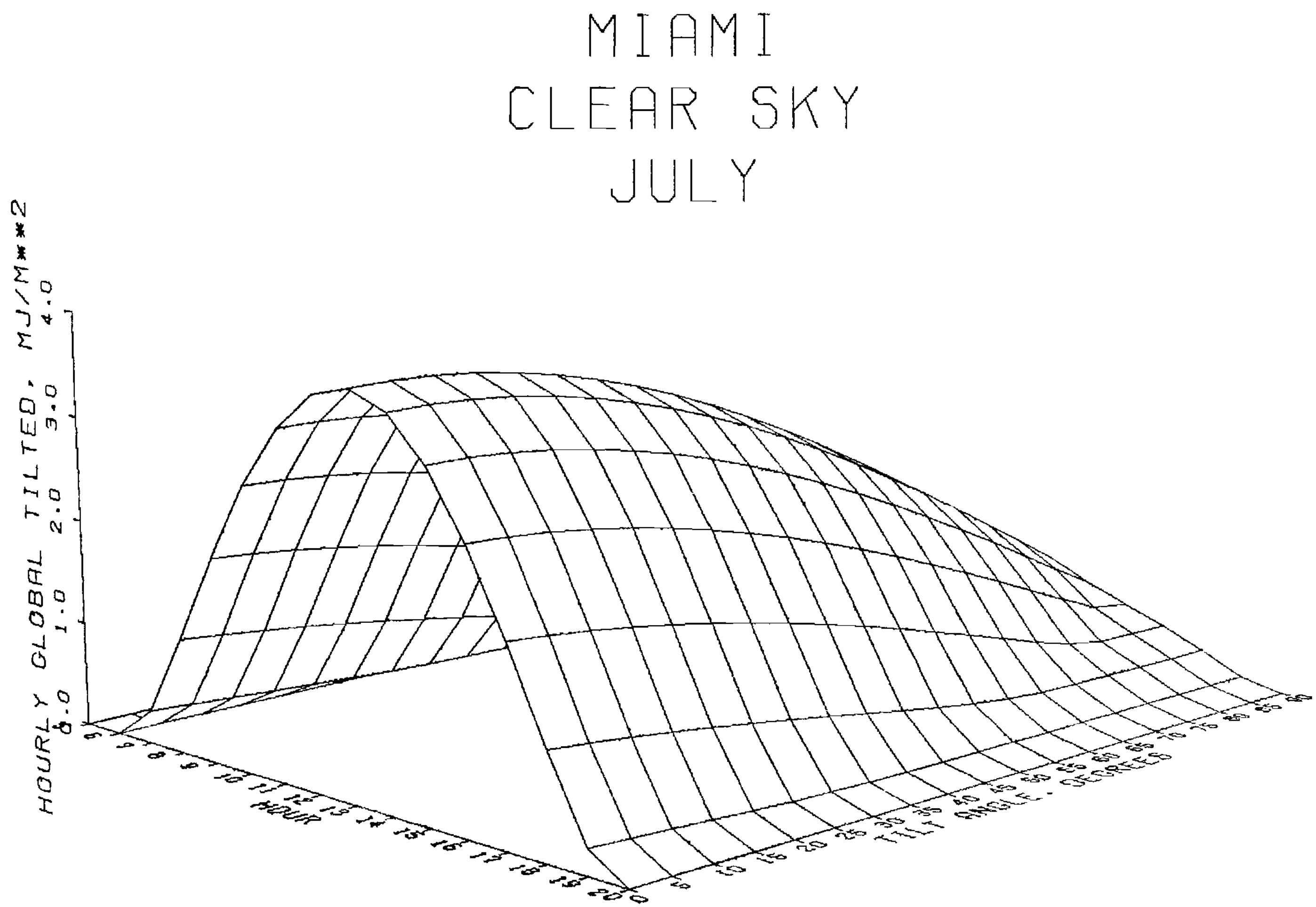

Figure 3.33. Miami Clear Sky July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.34. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JULY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.23	.22	.21	.19	.18	.17	.15	.14	.14	.13	.13	.12	.12	.12	.11	.11	.10	.10	.10
8	.75	.73	.71	.69	.66	.63	.59	.55	.51	.47	.43	.40	.36	.34	.32	.31	.30	.29	.28
9	1.28	1.27	1.24	1.21	1.18	1.14	1.10	1.04	.99	.93	.87	.80	.73	.66	.59	.52	.47	.45	.43
10	1.73	1.72	1.71	1.68	1.64	1.60	1.55	1.49	1.42	1.35	1.27	1.18	1.09	1.00	.90	.80	.70	.60	.55
11	2.08	2.07	2.06	2.04	2.00	1.95	1.90	1.83	1.76	1.68	1.58	1.49	1.38	1.27	1.16	1.04	.92	.79	.67
12	2.29	2.29	2.28	2.26	2.22	2.18	2.12	2.05	1.97	1.88	1.78	1.68	1.56	1.44	1.32	1.19	1.05	.92	.78
13	2.36	2.36	2.35	2.33	2.29	2.25	2.19	2.12	2.04	1.95	1.85	1.74	1.62	1.50	1.37	1.23	1.10	.96	.81
14	2.28	2.28	2.27	2.24	2.21	2.16	2.10	2.03	1.96	1.87	1.77	1.66	1.55	1.43	1.31	1.18	1.04	.91	.77
15	2.05	2.05	2.03	2.01	1.97	1.93	1.87	1.80	1.73	1.65	1.56	1.46	1.36	1.25	1.14	1.02	.90	.78	.66
16	1.69	1.68	1.67	1.64	1.60	1.56	1.51	1.45	1.38	1.31	1.23	1.15	1.06	.97	.88	.78	.68	.59	.54
17	1.23	1.22	1.19	1.17	1.13	1.09	1.05	1.00	.94	.89	.82	.76	.69	.62	.55	.49	.45	.43	.42
18	.70	.68	.66	.63	.61	.58	.54	.51	.47	.43	.40	.36	.33	.31	.30	.29	.28	.27	.26
19	.19	.18	.17	.16	.14	.13	.12	.12	.11	.11	.11	.10	.10	.10	.09	.09	.09	.08	.08
20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0.00	0.00	0.00	0.00	0.00

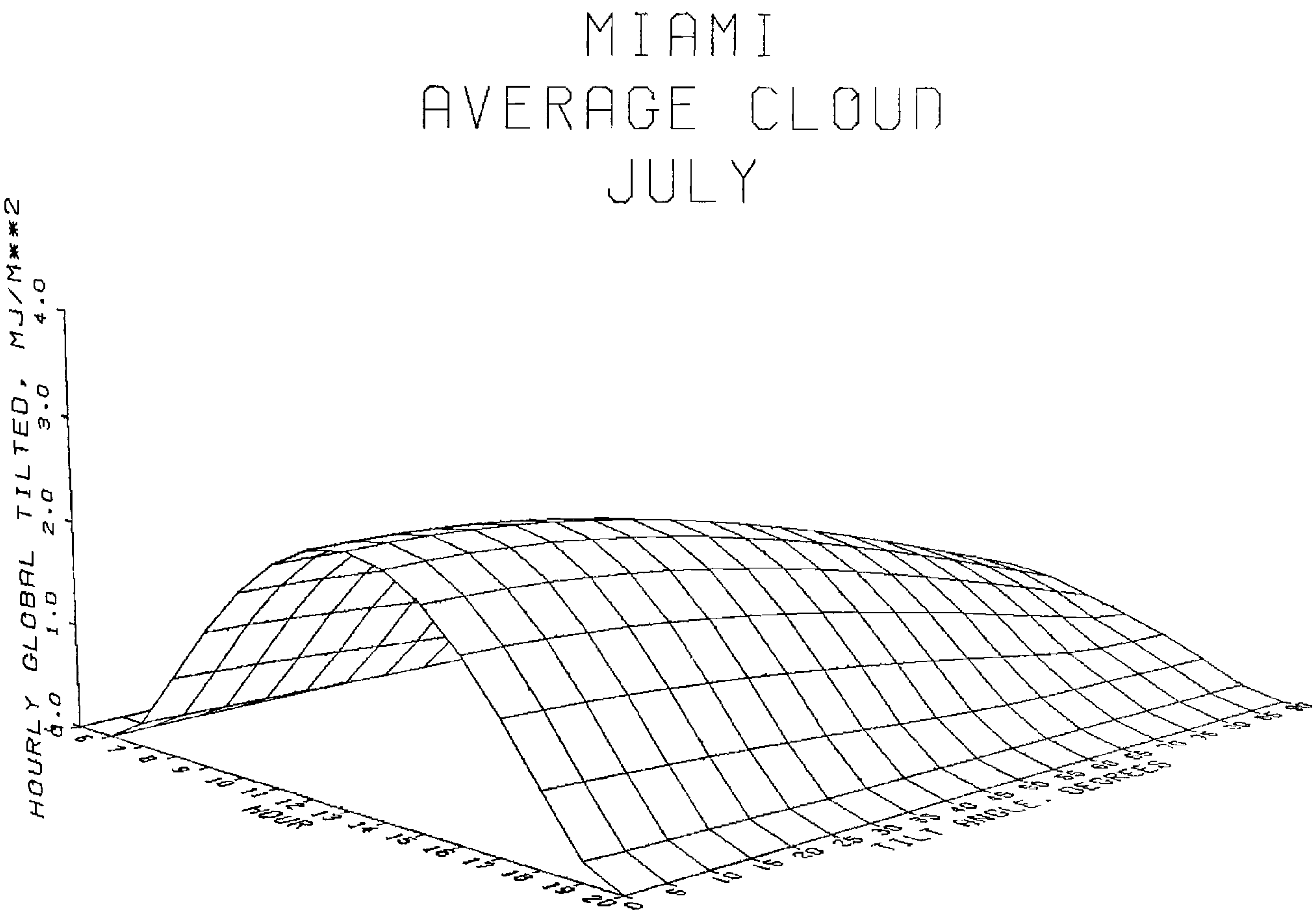

Figure 3.34. Miami Average Cloud July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.35. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

OCTOBER

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.05	.05	.06	.06	.06	.07	.07	.07	.07	.07	.08	.08	.08	.07	.07	.07	.07	.07	.07
8	.64	.67	.71	.74	.77	.79	.80	.82	.82	.83	.82	.82	.80	.79	.76	.74	.71	.67	.63
9	1.48	1.56	1.63	1.68	1.73	1.77	1.79	1.80	1.81	1.80	1.78	1.75	1.71	1.66	1.60	1.53	1.45	1.36	1.26
10	2.24	2.35	2.44	2.52	2.58	2.62	2.65	2.66	2.66	2.64	2.60	2.55	2.48	2.40	2.30	2.19	2.06	1.92	1.77
11	2.89	2.93	3.04	3.13	3.20	3.25	3.28	3.29	3.28	3.25	3.20	3.13	3.04	2.93	2.80	2.66	2.50	2.32	2.13
12	3.11	3.25	3.37	3.46	3.54	3.59	3.63	3.64	3.62	3.58	3.53	3.44	3.34	3.22	3.07	2.91	2.73	2.54	2.33
13	3.14	3.28	3.40	3.50	3.57	3.63	3.66	3.67	3.65	3.62	3.56	3.47	3.37	3.25	3.10	2.94	2.76	2.56	2.35
14	2.89	3.02	3.13	3.22	3.29	3.35	3.38	3.39	3.38	3.34	3.29	3.22	3.12	3.01	2.88	2.73	2.56	2.38	2.19
15	2.37	2.49	2.58	2.66	2.73	2.77	2.80	2.81	2.81	2.79	2.75	2.69	2.61	2.52	2.42	2.30	2.16	2.02	1.86
16	1.65	1.73	1.81	1.87	1.92	1.96	1.98	2.00	2.00	1.99	1.97	1.93	1.88	1.83	1.76	1.68	1.59	1.49	1.38
17	.81	.86	.90	.93	.96	.99	1.01	1.02	1.03	1.03	1.03	1.01	1.00	.97	.94	.91	.87	.82	.77
18	.11	.12	.13	.14	.14	.15	.15	.16	.16	.16	.16	.16	.16	.16	.16	.16	.15	.15	.14
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

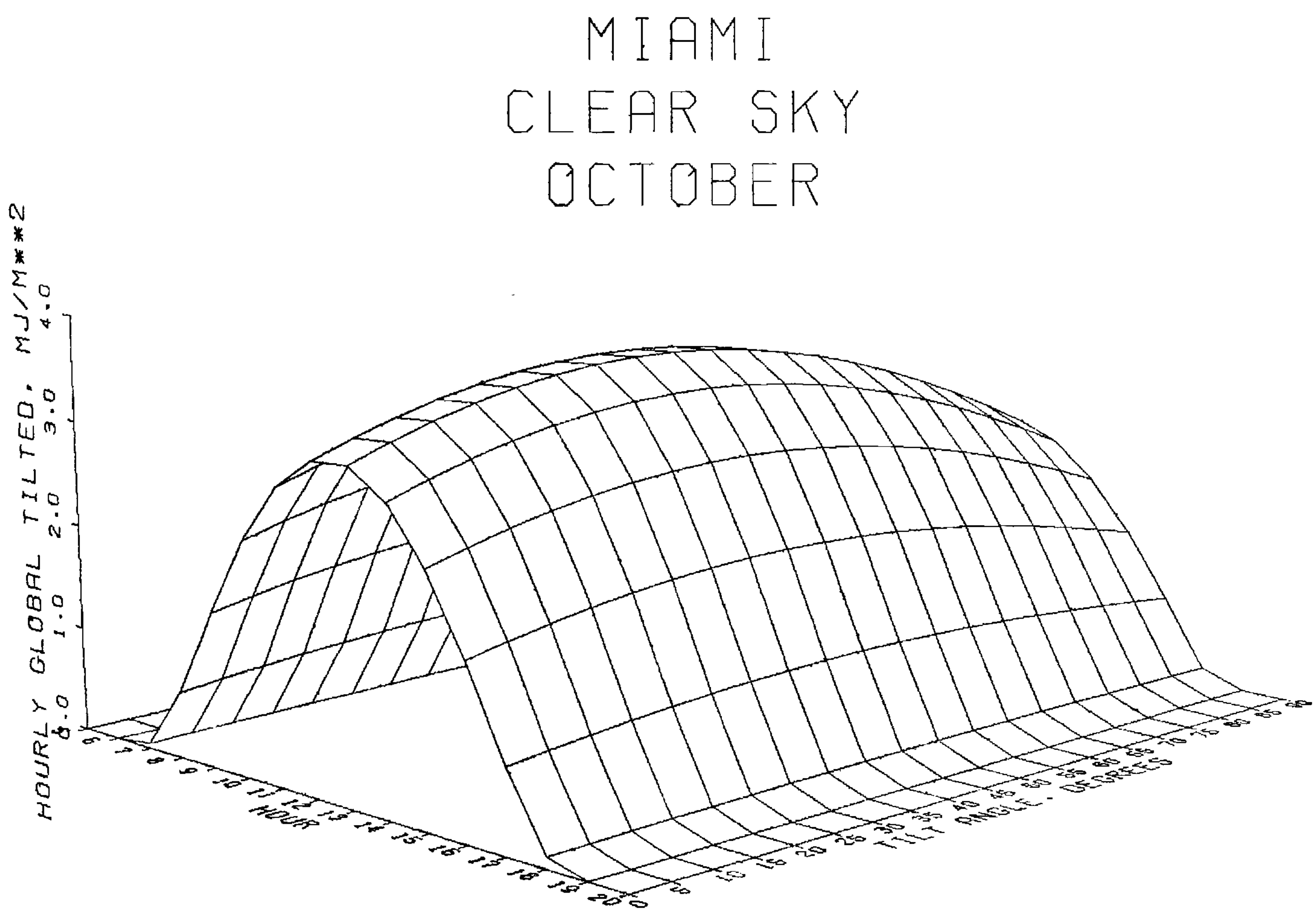

Figure 3.35. Miami Clear Sky October Hourly Global Tilted Radiation (Megajoules per Square Meter)

Table 3.36. MIAMI

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

OCTOBER

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.04	.04	.04	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.04	.04
8	.47	.49	.51	.52	.53	.54	.55	.55	.55	.55	.55	.54	.53	.51	.50	.48	.46	.44	.41
9	1.04	1.08	1.11	1.14	1.16	1.17	1.18	1.18	1.18	1.17	1.15	1.13	1.10	1.06	1.02	.98	.93	.87	.81
10	1.53	1.58	1.62	1.66	1.69	1.71	1.71	1.71	1.70	1.68	1.66	1.62	1.57	1.52	1.45	1.38	1.31	1.22	1.13
11	1.88	1.94	1.99	2.04	2.07	2.09	2.10	2.09	2.08	2.05	2.01	1.97	1.91	1.84	1.76	1.67	1.57	1.47	1.36
12	2.07	2.14	2.19	2.24	2.27	2.30	2.30	2.30	2.28	2.25	2.21	2.16	2.09	2.01	1.92	1.82	1.72	1.60	1.48
13	2.08	2.15	2.21	2.26	2.29	2.32	2.32	2.32	2.30	2.27	2.23	2.17	2.11	2.03	1.94	1.84	1.73	1.61	1.49
14	1.93	1.99	2.05	2.09	2.13	2.15	2.15	2.15	2.14	2.11	2.07	2.02	1.96	1.89	1.80	1.71	1.61	1.50	1.39
15	1.61	1.67	1.71	1.75	1.78	1.80	1.81	1.81	1.79	1.77	1.74	1.70	1.65	1.59	1.53	1.45	1.37	1.28	1.19
16	1.15	1.19	1.23	1.26	1.28	1.29	1.30	1.30	1.30	1.28	1.27	1.24	1.21	1.17	1.12	1.07	1.01	.95	.89
17	.59	.61	.63	.65	.67	.68	.68	.69	.69	.68	.68	.66	.65	.63	.61	.59	.56	.53	.50
18	.09	.09	.10	.10	.10	.11	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10	.09	.09
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

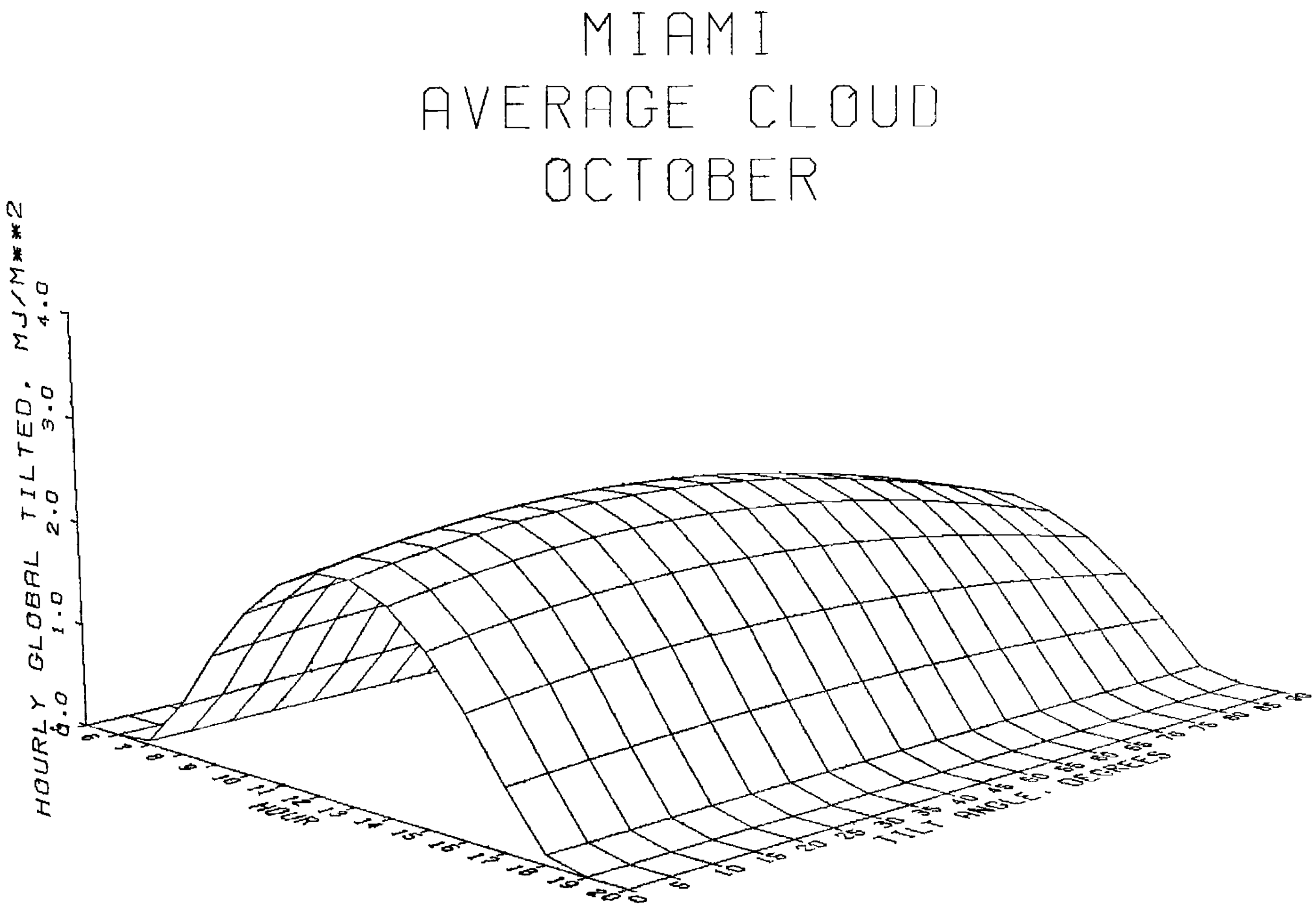

Figure 3.36. Miami Average Cloud October Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.37. **WASHINGTON**

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		TILT ANGLE (DEGREES)																		
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
MONTH	1	8.7	9.8	10.8	11.8	12.7	13.6	14.3	14.9	15.5	15.9	16.3	16.5	16.6	16.6	16.5	16.3	16.0	15.5	15.0
	2	12.6	13.7	14.8	15.9	16.8	17.6	18.3	18.8	19.3	19.6	19.8	19.9	19.8	19.6	19.3	18.8	18.2	17.6	16.8
	3	18.1	19.1	20.1	20.9	21.6	22.2	22.6	22.9	23.0	23.0	22.8	22.5	22.0	21.5	20.7	19.9	18.9	17.8	16.6
	4	23.7	24.4	24.9	25.4	25.6	25.7	25.6	25.4	25.0	24.5	23.8	23.0	22.0	21.0	19.8	18.4	17.0	15.5	13.9
	5	27.5	27.8	27.9	27.9	27.7	27.4	26.9	26.2	25.4	24.5	23.4	22.2	20.9	19.4	17.9	16.3	14.7	13.0	11.3
	6	26.5	26.6	26.6	26.4	26.0	25.5	24.9	24.1	23.2	22.2	21.1	19.9	18.5	17.1	15.7	14.2	12.7	11.1	9.7
	7	26.0	26.1	26.1	26.0	25.7	25.3	24.7	24.0	23.2	22.3	21.2	20.0	18.8	17.4	16.0	14.6	13.1	11.6	10.1
	8	25.1	25.6	25.9	26.1	26.1	26.0	25.7	25.3	24.7	23.9	23.1	22.1	21.0	19.8	18.4	17.0	15.5	14.0	12.4
	9	20.4	21.3	22.0	22.6	23.1	23.4	23.6	23.6	23.5	23.2	22.8	22.3	21.6	20.8	19.9	18.9	17.7	16.5	15.1
	10	14.8	16.0	17.0	17.9	18.7	19.4	19.9	20.4	20.7	20.8	20.9	20.8	20.6	20.2	19.7	19.1	18.4	17.5	16.6
	11	10.0	11.2	12.3	13.2	14.2	15.0	15.7	16.3	16.8	17.2	17.5	17.7	17.8	17.7	17.5	17.2	16.8	16.3	15.7
	12	7.8	8.9	9.9	10.9	11.8	12.6	13.4	14.0	14.6	15.0	15.4	15.7	15.8	15.8	15.8	15.6	15.3	15.0	14.5
ANNUAL MEAN		18.4	19.2	19.9	20.4	20.8	21.1	21.3	21.3	21.2	21.0	20.7	20.2	19.6	18.9	18.1	17.2	16.2	15.1	14.0

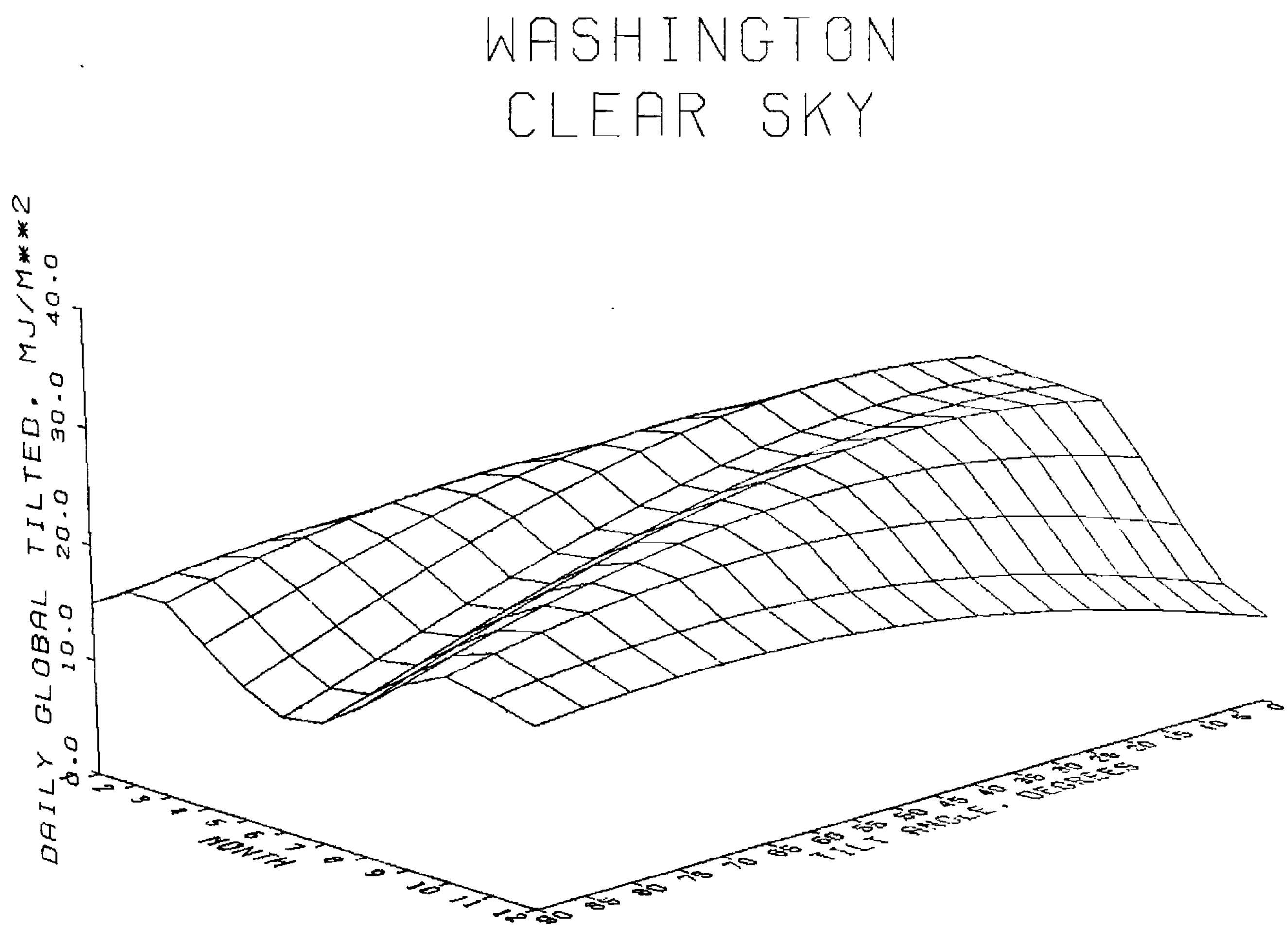

Figure 3.37. Washington Clear Sky Daily Global Tilted Radiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.38. **WASHINGTON**

DAILY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	1	6.1	6.6	7.1	7.6	8.0	8.4	8.8	9.0	9.3	9.5	9.6	9.6	9.6	9.6	9.5	9.3	9.1	8.8	8.5
	2	9.0	9.6	10.2	10.7	11.2	11.6	11.9	12.1	12.3	12.5	12.5	12.5	12.4	12.2	12.0	11.6	11.3	10.8	10.3
	3	12.7	13.2	13.7	14.1	14.5	14.7	14.9	15.0	15.0	14.9	14.8	14.5	14.2	13.8	13.3	12.7	12.1	11.4	10.7
	4	16.7	17.0	17.3	17.5	17.6	17.6	17.5	17.4	17.1	16.7	16.2	15.7	15.0	14.3	13.5	12.7	11.8	10.8	9.8
	5	19.2	19.4	19.5	19.4	19.3	19.1	18.7	18.3	17.7	17.1	16.4	15.6	14.8	13.9	12.9	11.9	10.8	9.8	8.7
MONTH	6	19.1	19.1	19.1	18.9	18.7	18.4	17.9	17.4	16.8	16.1	15.4	14.6	13.7	12.8	11.8	10.8	9.8	8.8	7.8
	7	18.7	18.8	18.8	18.7	18.5	18.2	17.8	17.3	16.8	16.1	15.4	14.7	13.8	12.9	12.0	11.0	10.0	9.0	8.0
	8	18.1	18.4	18.5	18.6	18.6	18.5	18.2	17.9	17.5	17.0	16.4	15.7	15.0	14.2	13.3	12.4	11.4	10.4	9.3
	9	15.0	15.5	15.9	16.3	16.5	16.7	16.7	16.7	16.6	16.4	16.0	15.7	15.2	14.6	14.0	13.2	12.5	11.6	10.7
	10	11.3	11.9	12.6	13.1	13.6	14.0	14.3	14.5	14.7	14.7	14.7	14.6	14.4	14.1	13.7	13.3	12.8	12.2	11.5
	11	7.3	8.0	8.6	9.1	9.6	10.0	10.4	10.7	10.9	11.1	11.2	11.3	11.2	11.2	11.0	10.8	10.5	10.1	9.7
	12	5.6	6.2	6.7	7.1	7.6	8.0	8.3	8.6	8.9	9.1	9.2	9.3	9.3	9.3	9.2	9.1	8.9	8.7	8.4
ANNUAL MEAN		13.2	13.6	14.0	14.3	14.5	14.6	14.6	14.6	14.5	14.3	14.0	13.6	13.2	12.7	12.2	11.6	10.9	10.2	9.5

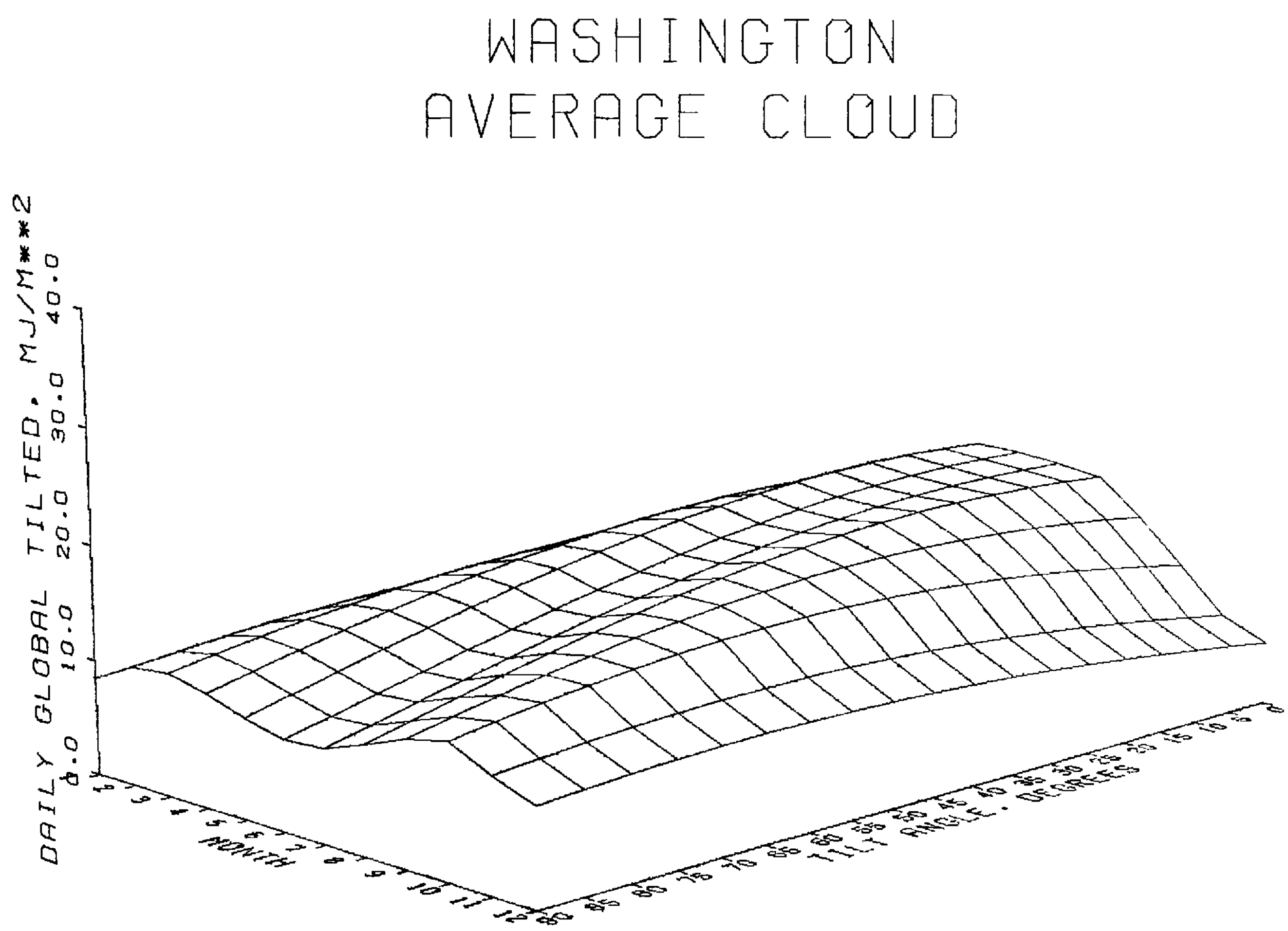

Figure 3.38. Washington Average Cloud Daily Global Tilted Radiation (Megajoules per Square Meter) versus Month and Tilt Angle.

Table 3.39. WASHINGTON

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	.005	.052	.064	.038	.011	0.000	0.000	0.000	0.000
	7	0.000	0.000	.014	.123	.218	.244	.215	.160	.078	.019	0.000	0.000
	8	.009	.042	.148	.278	.361	.414	.399	.341	.260	.164	.062	.014
	9	.118	.183	.285	.397	.476	.556	.555	.487	.404	.303	.200	.126
	10	.235	.292	.384	.486	.562	.668	.677	.598	.510	.401	.296	.232
	11	.310	.365	.452	.547	.622	.746	.764	.676	.582	.464	.358	.298
HOUR	12	.352	.407	.491	.581	.654	.789	.814	.720	.619	.494	.387	.332
	13	.361	.419	.500	.585	.657	.795	.824	.728	.622	.491	.384	.334
	14	.339	.401	.481	.561	.631	.764	.795	.701	.590	.456	.350	.306
	15	.284	.353	.433	.508	.576	.697	.728	.639	.524	.387	.283	.245
	16	.194	.273	.356	.428	.494	.597	.623	.544	.424	.283	.179	.146
	17	.063	.156	.246	.318	.386	.464	.485	.415	.286	.136	.041	.025
	18	0.000	.022	.097	.176	.248	.303	.315	.251	.108	.008	0.000	0.000
	19	0.000	0.000	.002	.024	.081	.120	.122	.062	.002	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	.005	.005	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		2.27	2.91	3.89	5.02	6.02	7.23	7.36	6.33	5.01	3.61	2.54	2.06

Figure 3.39. Washington Clear Sky Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.40. WASHINGTON

HOURLY DIFFUSE RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	.005	.056	.065	.038	.011	0.000	0.000	0.000	0.000
7	0.000	0.000	.015	.141	.254	.259	.224	.172	.084	.020	0.000	0.000
8	.009	.047	.178	.341	.437	.450	.427	.383	.294	.186	.070	.015
9	.140	.226	.363	.500	.585	.610	.599	.555	.469	.356	.242	.151
10	.298	.377	.501	.620	.697	.736	.735	.687	.599	.478	.373	.296
11	.405	.480	.596	.701	.773	.823	.831	.779	.686	.558	.457	.390
12	.465	.540	.650	.745	.813	.871	.885	.830	.731	.595	.497	.439
13	.479	.557	.664	.751	.817	.878	.897	.840	.735	.592	.493	.443
14	.447	.531	.638	.719	.784	.844	.865	.809	.696	.547	.446	.401
15	.368	.463	.570	.649	.714	.769	.790	.736	.616	.461	.354	.315
16	.242	.350	.462	.542	.609	.656	.675	.623	.493	.330	.215	.178
17	.072	.189	.309	.395	.469	.507	.522	.470	.326	.152	.045	.028
18	0.000	.024	.112	.203	.292	.326	.334	.276	.116	.008	0.000	0.000
19	0.000	0.000	.001	.026	.089	.124	.125	.064	.002	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	.005	.005	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	2.93	3.78	5.06	6.34	7.39	7.92	7.95	7.24	5.85	4.28	3.19	2.66

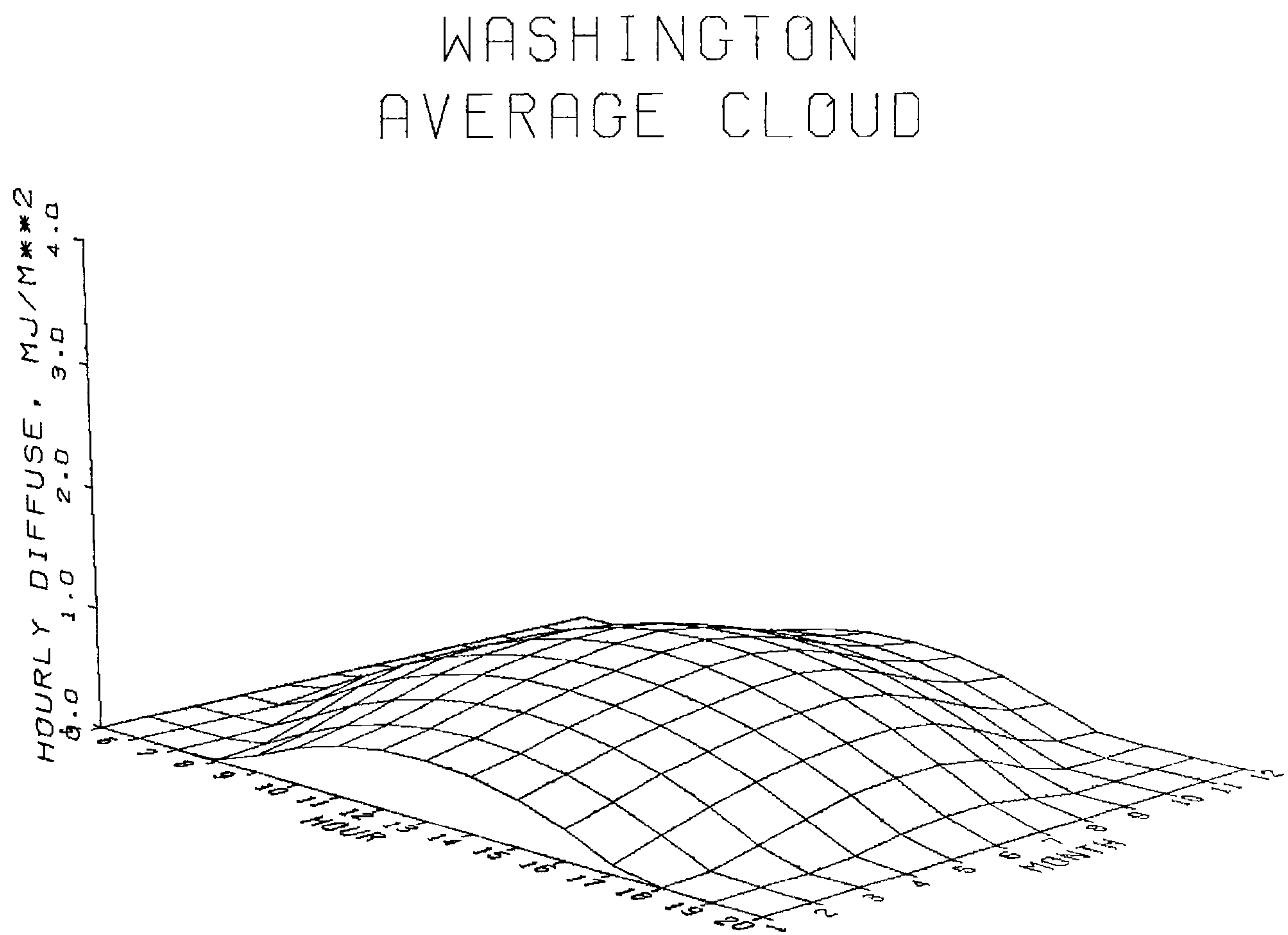

Figure 3.40. Washington Average Cloud Hourly Diffuse Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.41. WASHINGTON

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

	MONTH											
HOUR	1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	.047	.414	.364	.211	.079	.001	0.000	0.000	0.000
7	0.000	0.000	.136	1.002	1.505	1.195	1.027	.978	.565	.165	.001	0.000
8	.088	.405	1.261	1.941	2.158	1.768	1.654	1.797	1.613	1.254	.568	.141
9	1.043	1.549	2.087	2.432	2.529	2.127	2.047	2.259	2.189	2.014	1.603	1.135
10	1.840	2.178	2.510	2.706	2.746	2.350	2.290	2.527	2.504	2.405	2.136	1.866
11	2.229	2.502	2.737	2.859	2.871	2.483	2.436	2.680	2.676	2.607	2.406	2.218
12	2.413	2.657	2.847	2.933	2.930	2.549	2.510	2.757	2.756	2.692	2.517	2.375
13	2.452	2.698	2.873	2.942	2.935	2.558	2.525	2.771	2.761	2.684	2.507	2.386
14	2.359	2.636	2.822	2.890	2.887	2.511	2.483	2.725	2.695	2.582	2.373	2.255
15	2.103	2.453	2.680	2.765	2.776	2.403	2.377	2.611	2.540	2.355	2.069	1.941
16	1.590	2.083	2.403	2.535	2.581	2.213	2.190	2.404	2.253	1.920	1.466	1.291
17	.586	1.354	1.886	2.126	2.247	1.907	1.884	2.047	1.732	1.064	.385	.251
18	.002	.219	.860	1.366	1.664	1.417	1.392	1.426	.758	.073	0.000	0.000
19	0.000	0.000	.016	.220	.629	.650	.627	.407	.013	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	.004	.032	.028	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	16.71	20.73	25.12	28.76	30.88	26.53	25.68	27.47	25.06	21.82	18.03	15.86

Figure 3.41. Washington Clear Sky Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.42. WASHINGTON

HOURLY DIRECT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

HOUR	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
5	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	.026	.229	.210	.122	.046	.001	0.000	0.000	0.000
7	0.000	0.000	.073	.554	.831	.691	.594	.565	.336	.103	.001	0.000
8	.043	.217	.675	1.072	1.192	1.022	.956	1.038	.960	.778	.314	.072
9	.514	.829	1.118	1.344	1.397	1.229	1.183	1.306	1.302	1.250	.886	.579
10	.907	1.166	1.344	1.495	1.517	1.358	1.324	1.460	1.490	1.492	1.180	.952
11	1.099	1.340	1.465	1.580	1.586	1.435	1.408	1.549	1.592	1.618	1.329	1.131
12	1.189	1.423	1.525	1.620	1.619	1.473	1.451	1.593	1.640	1.670	1.391	1.211
13	1.209	1.445	1.539	1.625	1.622	1.478	1.460	1.601	1.643	1.665	1.385	1.217
14	1.163	1.412	1.511	1.597	1.595	1.452	1.435	1.575	1.603	1.602	1.311	1.150
15	1.037	1.314	1.435	1.527	1.534	1.389	1.374	1.509	1.511	1.461	1.143	.990
16	.784	1.115	1.287	1.401	1.426	1.279	1.266	1.389	1.341	1.191	.810	.658
17	.289	.725	1.010	1.175	1.241	1.102	1.089	1.183	1.031	.660	.213	.128
18	.001	.117	.461	.755	.919	.819	.804	.824	.451	.046	0.000	0.000
19	0.000	0.000	.008	.121	.347	.376	.363	.235	.008	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	.002	.019	.016	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL	8.24	11.10	13.45	15.89	17.06	15.33	14.85	15.87	14.91	13.54	9.96	8.09

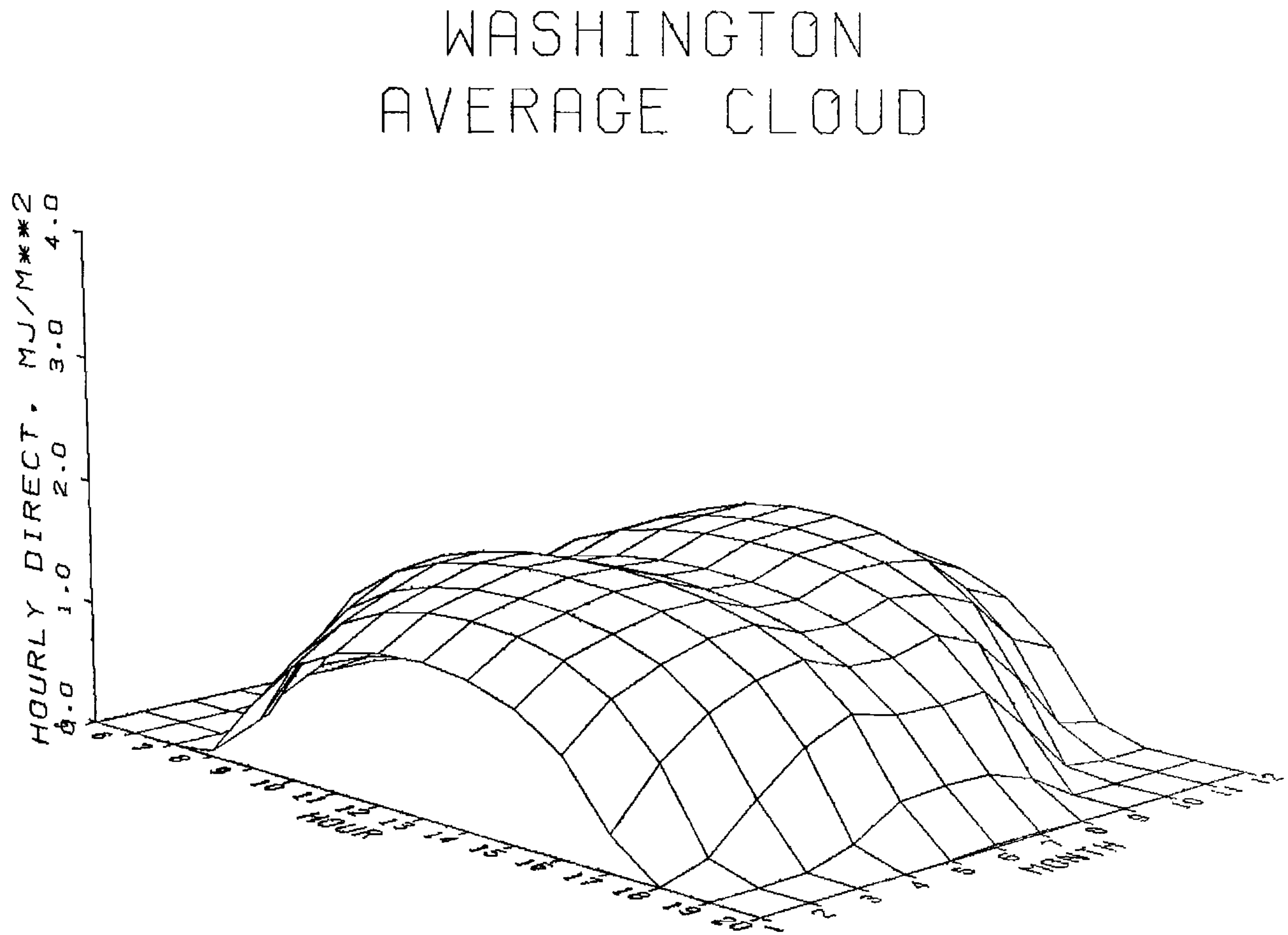

Figure 3.42. Washington Average Cloud Hourly Direct Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.43. WASHINGTON

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	.008	.107	.123	.068	.018	0.000	0.000	0.000	0.000
	7	0.000	0.000	.025	.319	.653	.626	.513	.382	.169	.034	0.000	0.000
	8	.014	.088	.426	1.003	1.374	1.290	1.171	1.072	.786	.452	.137	.024
	9	.305	.579	1.103	1.727	2.083	1.957	1.850	1.794	1.493	1.089	.630	.338
	10	.807	1.167	1.750	2.360	2.687	2.535	2.449	2.428	2.118	1.666	1.144	.814
	11	1.236	1.656	2.257	2.831	3.129	2.966	2.903	2.906	2.578	2.084	1.532	1.199
HOUR	12	1.504	1.964	2.566	3.097	3.371	3.210	3.171	3.184	2.829	2.293	1.728	1.419
	13	1.568	2.054	2.646	3.133	3.393	3.246	3.228	3.239	2.849	2.273	1.710	1.435
	14	1.421	1.918	2.492	2.938	3.193	3.070	3.069	3.065	2.634	2.026	1.478	1.247
	15	1.080	1.570	2.115	2.528	2.787	2.697	2.709	2.677	2.205	1.577	1.063	.885
	16	.608	1.053	1.556	1.939	2.210	2.163	2.180	2.110	1.603	.981	.537	.414
	17	.139	.459	.883	1.233	1.516	1.518	1.534	1.419	.901	.351	.085	.048
	18	0.000	.042	.243	.516	.787	.840	.848	.694	.247	.013	0.000	0.000
	19	0.000	0.000	.002	.046	.180	.256	.255	.123	.002	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	.001	.008	.007	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		8.68	12.55	18.06	23.68	27.47	26.51	25.96	25.11	20.41	14.84	10.04	7.82

Figure 3.43. Washington Clear Sky Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.44. WASHINGTON

GLOBAL HORIZONTAL RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	.007	.086	.099	.055	.015	0.000	0.000	0.000	0.000
	7	0.000	0.000	.021	.250	.494	.480	.397	.301	.138	.029	0.000	0.000
	8	.012	.072	.327	.742	.997	.956	.873	.805	.607	.364	.111	.020
	9	.232	.438	.801	1.235	1.473	1.420	1.348	1.311	1.117	.843	.480	.259
	10	.580	.845	1.233	1.655	1.871	1.815	1.759	1.745	1.555	1.263	.841	.593
	11	.862	1.172	1.563	1.963	2.158	2.107	2.067	2.068	1.874	1.563	1.106	.850
HOUR	12	1.033	1.374	1.762	2.135	2.315	2.271	2.247	2.255	2.046	1.711	1.238	.993
	13	1.074	1.433	1.813	2.159	2.329	2.295	2.286	2.291	2.060	1.697	1.226	1.004
	14	.980	1.344	1.714	2.033	2.199	2.176	2.179	2.175	1.912	1,522	1.069	.882
	15	.761	1.115	1.471	1.765	1.936	1.925	1.936	1.914	1.616	1.199	.785	.641
	16	.446	.768	1.104	1.377	1.557	1.561	1.575	1.528	1.195	.764	.413	.315
	17	.109	.352	.651	.900	1.093	1.116	1.128	1.050	.691	.285	.069	.039
	18	0.000	.035	.191	.396	.590	.636	.642	.532	.199	.012	0.000	0.000
	19	0.000	0.000	.002	.038	.143	.203	.202	.100	.002	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	.006	.006	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		6.09	8.95	12.65	16.66	19.24	19.07	18.70	18.09	15.01	11.25	7.34	5.60

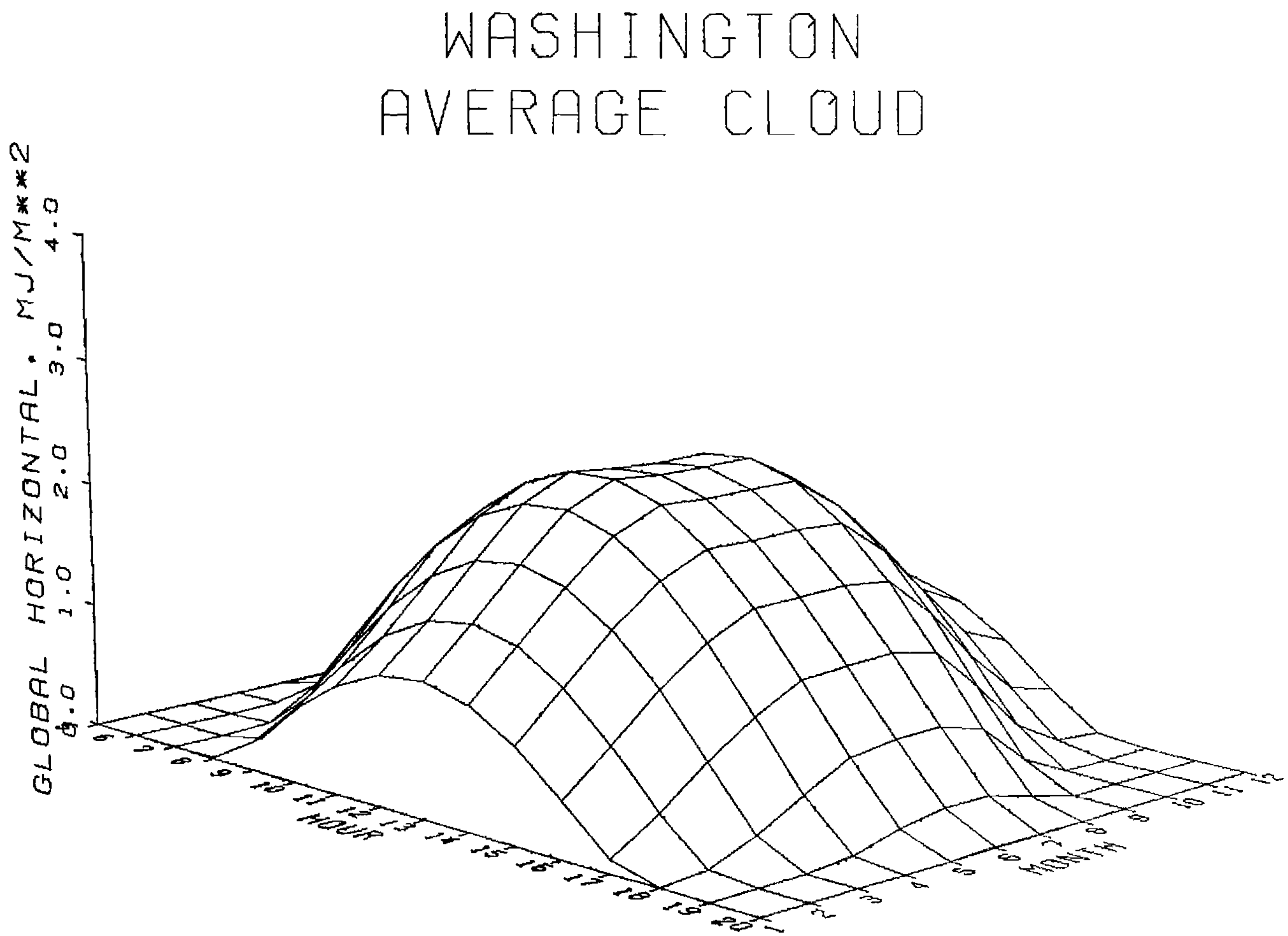

Figure 3.44. Washington Average Cloud Global Horizontal Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.45. **WASHINGTON**

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	.004	.046	.057	.034	.010	0.000	0.000	0.000	0.000
	7	0.000	0.000	.031	.227	.364	.330	.273	.234	.159	.056	0.000	0.000
	8	.041	.173	.533	.918	1.063	.930	.852	.879	.830	.667	.297	.070
	9	.652	.965	1.377	1.736	1.833	1.616	1.546	1.657	1.656	1.522	1.140	.745
	10	1.486	1.797	2.186	2.478	2.519	2.244	2.194	2.374	2.402	2.273	1.898	1.547
	11	2.122	2.458	2.819	3.038	3.031	2.725	2.700	2.927	2.957	2.809	2.441	2.128
HOUR	12	2.504	2.866	3.204	3.357	3.314	3.000	3.002	3.252	3.262	3.077	2.711	2.447
	13	2.594	2.986	3.304	3.401	3.340	3.041	3.067	3.315	3.285	3.052	2.686	2.472
	14	2.386	2.806	3.111	3.166	3.105	2.841	2.887	3.112	3.025	2.736	2.367	2.200
	15	1.895	2.343	2.642	2.676	2.633	2.424	2.483	2.661	2.507	2.158	1.783	1.658
	16	1.172	1.640	1.943	1.982	1.975	1.837	1.900	2.012	1.786	1.380	.993	.885
	17	.326	.784	1.104	1.172	1.213	1.158	1.216	1.246	.962	.526	.191	.131
	18	.001	.086	.304	.410	.482	.507	.548	.504	.238	.023	0.000	0.000
	19	0.000	0.000	.003	.024	.074	.110	.118	.062	.002	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	.005	.004	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		15.18	18.90	22.56	24.59	24.99	22.83	22.82	24.25	23.07	20.28	16.51	14.28

Figure 3.45. Washington Clear Sky Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.46. WASHINGTON

LATITUDE TILT RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

		MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	.005	.050	.058	.034	.010	0.000	0.000	0.000	0.000
	7	0.000	0.000	.023	.191	.320	.296	.247	.206	.128	.042	0.000	0.000
	8	.024	.115	.373	.674	.799	.725	.667	.673	.618	.488	.195	.043
	9	.394	.630	.924	1.209	1.299	1.191	1.141	1.201	1.188	1.094	.747	.457
	10	.895	1.158	1.433	1.681	1.735	1.608	1.573	1.676	1.691	1.614	1.234	.947
	11	1.270	1.570	1.824	2.033	2.056	1.923	1.906	2.037	2.062	1.983	1.579	1.297
HOUR	12	1.494	1.821	2.060	2.232	2.233	2.103	2.104	2.248	2.263	2.166	1.749	1.488
	13	1.546	1.894	2.122	2.259	2.249	2.130	2.146	2.289	2.279	2.149	1.733	1.503
	14	1.425	1.784	2.004	2.113	2.102	2.000	2.029	2.157	2.106	1.933	1.533	1.340
	15	1.137	1.499	1.715	1.806	1.807	1.727	1.764	1.864	1.762	1.535	1.161	1.014
	16	.708	1.059	1.282	1.367	1.390	1.339	1.378	1.437	1.277	.994	.652	.543
	17	.197	.514	.749	.843	.897	.882	.918	.924	.711	.386	.125	.080
	18	.001	.057	.217	.325	.404	.427	.452	.408	.188	.017	0.000	0.000
	19	0.000	0.000	.002	.025	.080	.112	.117	.061	.001	0.000	0.000	0.000
	20	0.000	0.000	0.000	0.000	0.000	.004	.004	0.000	0.000	0.000	0.000	0.000
DAILY TOTAL		9.09	12.10	14.73	16.76	17.42	16.53	16.48	17.19	16.27	14.40	10.71	8.71

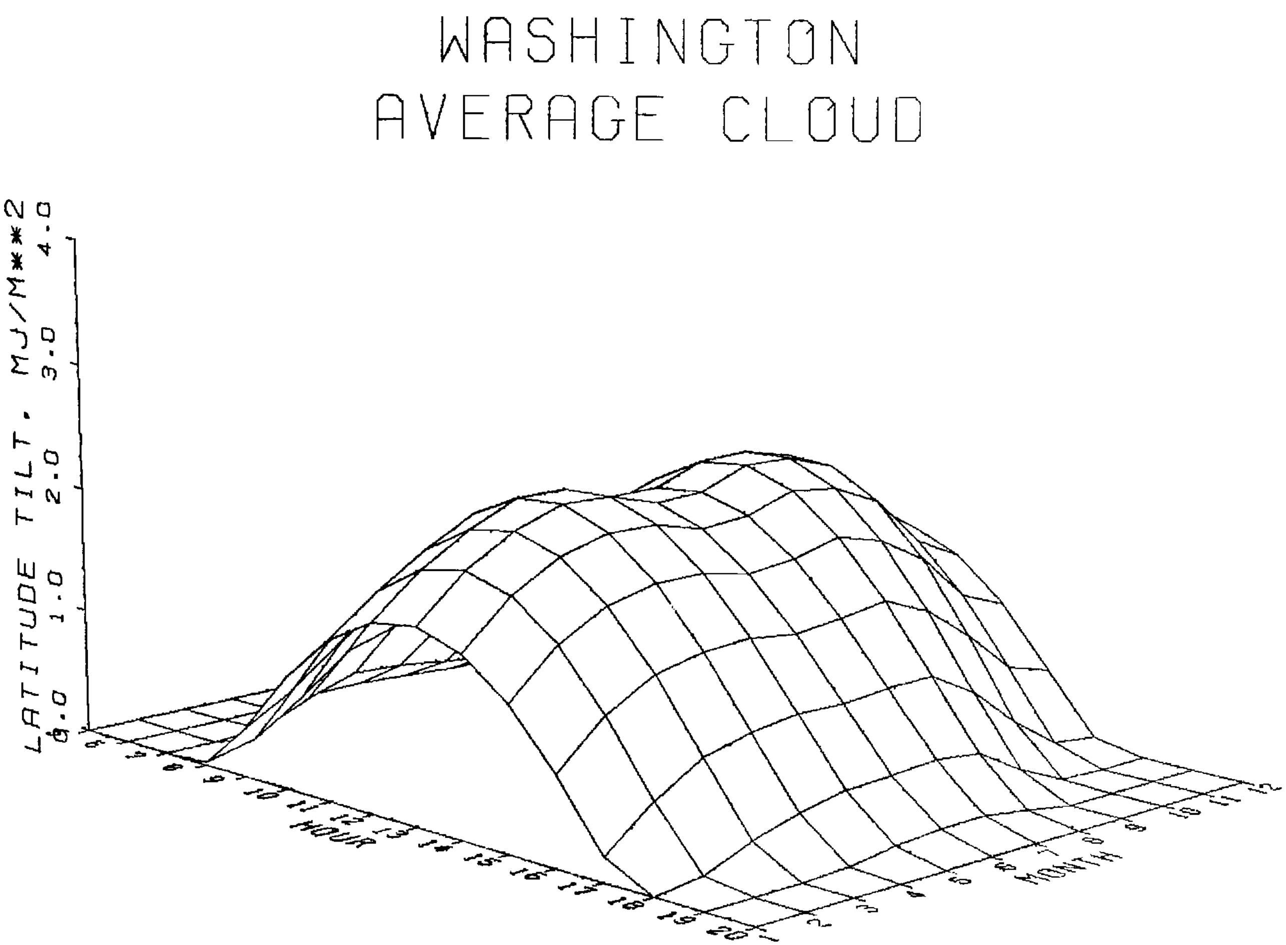

Figure 3.46. Washington Average Cloud Latitude Tilt Radiation (Megajoules per Square Meter) versus Hour and Month.

Table 3.47. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.01	.02	.02	.03	.03	.03	.04	.04	.04	.04	.05	.05	.05	.05	.05	.05	.05	.05	.05
9	.31	.36	.41	.46	.51	.55	.60	.63	.67	.69	.72	.74	.75	.76	.76	.76	.76	.75	.73
10	.81	.92	1.03	1.13	1.22	1.31	1.39	1.46	1.52	1.56	1.60	1.63	1.65	1.66	1.65	1.63	1.61	1.57	1.52
11	1.24	1.39	1.53	1.67	1.79	1.90	2.00	2.09	2.16	2.22	2.27	2.30	2.31	2.31	2.29	2.26	2.21	2.15	2.07
12	1.50	1.68	1.84	2.00	2.14	2.27	2.38	2.47	2.55	2.62	2.66	2.69	2.70	2.69	2.67	2.62	2.56	2.48	2.39
13	1.57	1.75	1.92	2.08	2.22	2.35	2.47	2.56	2.65	2.71	2.76	2.78	2.79	2.78	2.75	2.71	2.64	2.56	2.46
14	1.42	1.59	1.75	1.90	2.03	2.15	2.26	2.36	2.43	2.50	2.54	2.57	2.58	2.57	2.55	2.51	2.45	2.38	2.29
15	1.03	1.22	1.35	1.47	1.59	1.69	1.78	1.86	1.93	1.99	2.03	2.06	2.03	2.08	2.06	2.04	2.00	1.94	1.88
16	.61	.70	.79	.87	.95	1.02	1.09	1.15	1.20	1.24	1.27	1.30	1.32	1.33	1.33	1.32	1.30	1.27	1.24
17	.14	.17	.20	.22	.25	.27	.30	.32	.33	.35	.36	.37	.38	.39	.39	.39	.39	.39	.38
18	0.00	0.00	0.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

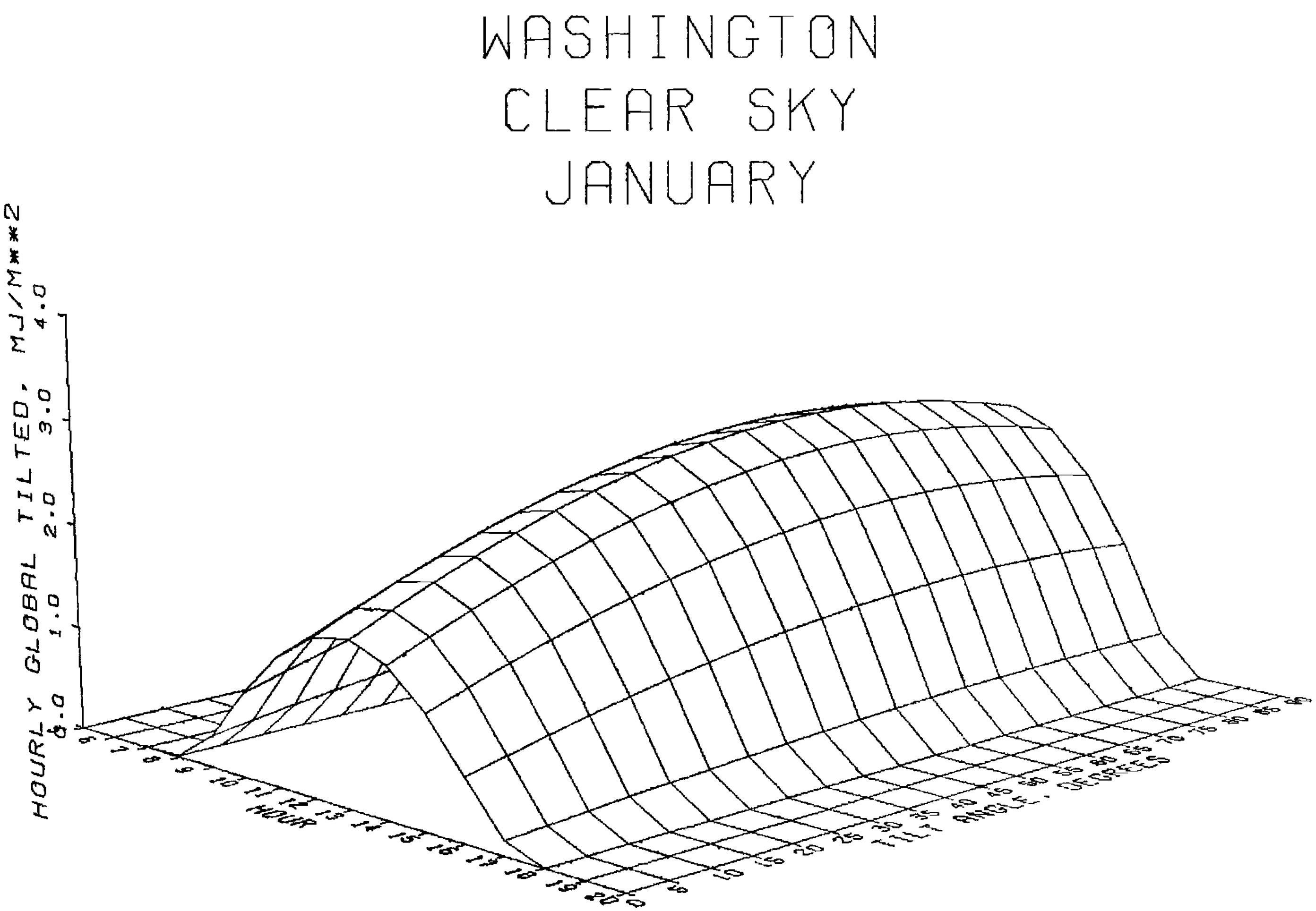

Figure 3.47. Washington Clear Sky January Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.48. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JANUARY

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	.01	.01	.02	.02	.02	.02	.02	.02	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
9	.23	.26	.29	.31	.33	.35	.37	.39	.40	.41	.42	.43	.44	.44	.44	.43	.43	.42	.41
10	.58	.64	.69	.74	.78	.82	.86	.89	.91	.93	.95	.96	.96	.96	.95	.93	.91	.89	.86
11	.86	.94	1.01	1.07	1.13	1.18	1.23	1.27	1.30	1.32	1.33	1.34	1.34	1.33	1.32	1.29	1.26	1.22	1.17
12	1.03	1.12	1.20	1.27	1.34	1.40	1.45	1.49	1.52	1.55	1.56	1.57	1.56	1.55	1.53	1.50	1.46	1.41	1.35
13	1.07	1.16	1.25	1.32	1.39	1.45	1.50	1.54	1.58	1.60	1.62	1.62	1.62	1.60	1.58	1.55	1.50	1.45	1.39
14	.98	1.06	1.14	1.21	1.27	1.33	1.38	1.42	1.45	1.48	1.49	1.50	1.50	1.48	1.46	1.43	1.40	1.35	1.30
15	.76	.83	.89	.95	1.01	1.05	1.10	1.13	1.16	1.18	1.20	1.21	1.21	1.20	1.19	1.17	1.14	1.10	1.06
16	.45	.49	.53	.57	.61	.64	.67	.70	.72	.74	.75	.76	.77	.77	.76	.75	.74	.72	.70
17	.11	.12	.14	.15	.16	.17	.18	.19	.20	.21	.21	.22	.22	.22	.22	.22	.22	.22	.21
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

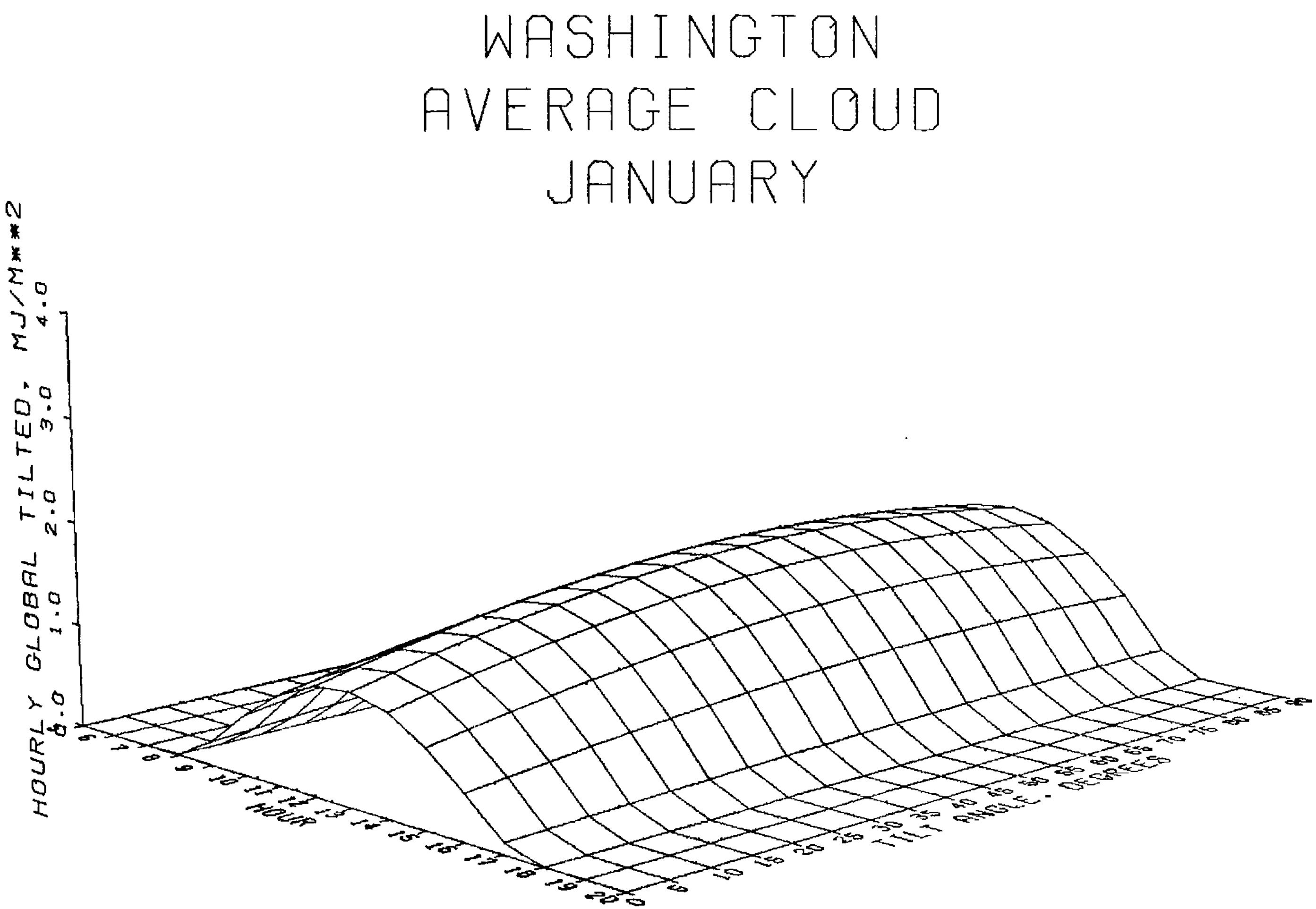

Figure 3.48. Washington Average Cloud January Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.49. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

APRIL

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	7	.32	.31	.31	.30	.29	.27	.26	.25	.23	.22	.20	.18	.17	.15	.14	.12	.11	.10	.09
	8	1.00	1.02	1.02	1.02	1.02	1.00	.99	.96	.93	.90	.86	.82	.77	.72	.66	.60	.54	.48	.41
	9	1.73	1.77	1.80	1.82	1.84	1.83	1.82	1.80	1.77	1.72	1.67	1.60	1.53	1.45	1.36	1.26	1.15	1.04	.93
	10	2.36	2.43	2.49	2.54	2.57	2.58	2.58	2.56	2.52	2.47	2.41	2.32	2.23	2.12	2.00	1.87	1.73	1.58	1.41
	11	2.83	2.93	3.01	3.07	3.12	3.14	3.14	3.13	3.09	3.04	2.96	2.87	2.76	2.64	2.49	2.34	2.17	1.98	1.79
HOUR	12	3.10	3.21	3.30	3.38	3.43	3.46	3.47	3.45	3.42	3.36	3.28	3.18	3.07	2.93	2.78	2.60	2.42	2.22	2.01
	13	3.13	3.25	3.34	3.42	3.47	3.50	3.51	3.50	3.46	3.40	3.33	3.23	3.11	2.97	2.81	2.64	2.45	2.25	2.04
	14	2.94	3.04	3.13	3.20	3.24	3.27	3.27	3.26	3.22	3.17	3.09	3.00	2.88	2.75	2.61	2.44	2.27	2.08	1.88
	15	2.53	2.61	2.68	2.73	2.76	2.78	2.78	2.76	2.72	2.67	2.60	2.52	2.42	2.30	2.18	2.04	1.88	1.72	1.55
	16	1.94	1.99	2.03	2.06	2.08	2.08	2.07	2.05	2.02	1.97	1.91	1.84	1.76	1.67	1.57	1.46	1.34	1.22	1.09
	17	1.23	1.25	1.27	1.27	1.27	1.26	1.25	1.22	1.19	1.16	1.11	1.06	1.00	.94	.87	.80	.73	.65	.57
	18	.52	.51	.51	.50	.49	.47	.46	.44	.42	.39	.37	.34	.31	.29	.26	.23	.20	.18	.16
	19	.05	.04	.04	.04	.04	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

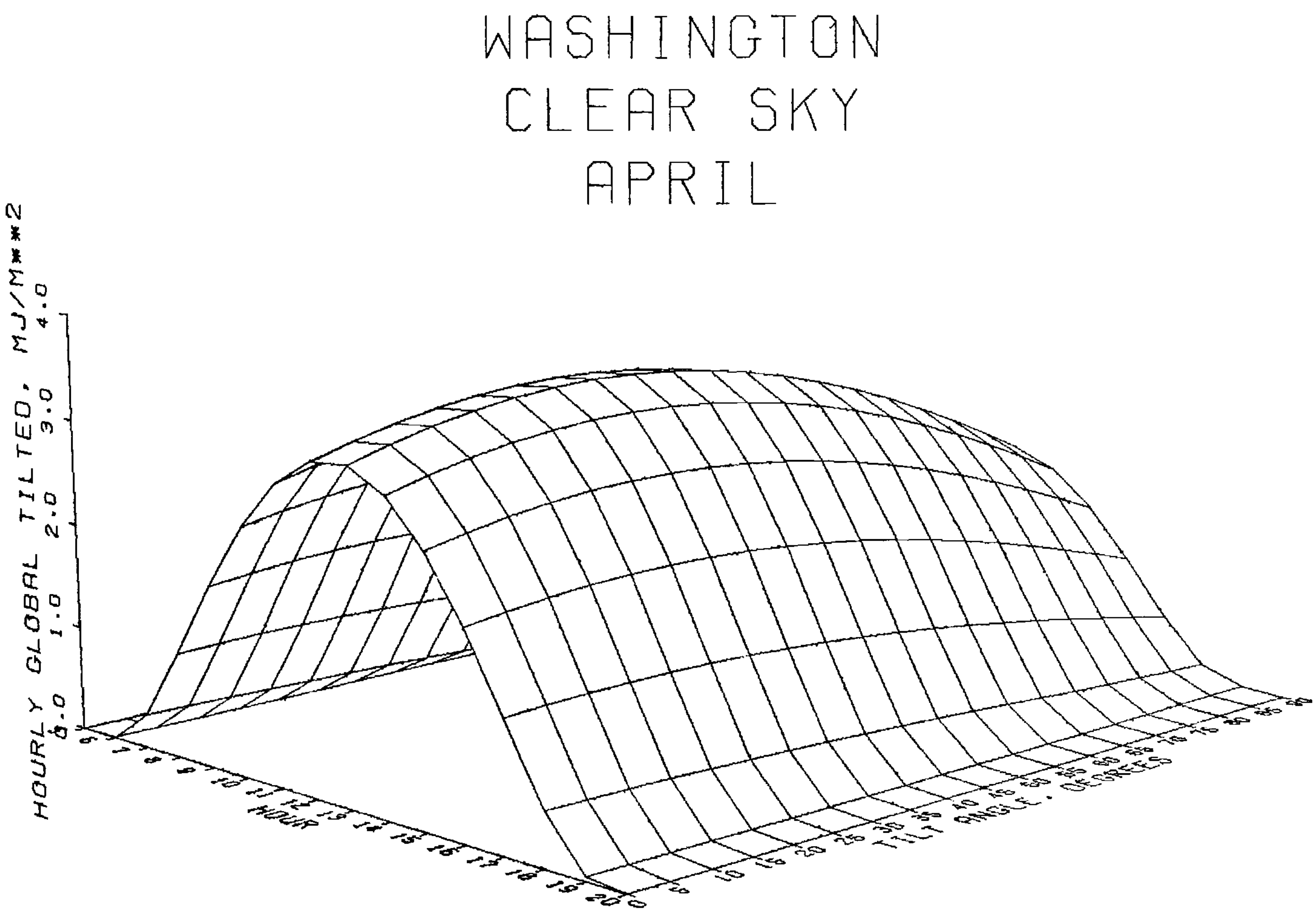

Figure 3.49. Washington Clear Sky April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.50. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

APRIL

TILT ANGLE (DEGREES)

HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.25	.25	.24	.24	.23	.22	.21	.21	.19	.18	.17	.16	.15	.14	.13	.12	.11	.10	.10
8	.74	.75	.75	.75	.74	.74	.72	.71	.69	.66	.64	.61	.58	.54	.50	.46	.42	.38	.34
9	1.24	1.26	1.28	1.29	1.29	1.28	1.27	1.26	1.23	1.20	1.16	1.12	1.07	1.02	.96	.89	.83	.75	.68
10	1.66	1.70	1.73	1.75	1.76	1.76	1.76	1.74	1.71	1.68	1.63	1.58	1.51	1.44	1.36	1.28	1.19	1.09	.99
11	1.96	2.02	2.06	2.09	2.11	2.12	2.11	2.10	2.07	2.03	1.98	1.92	1.85	1.76	1.67	1.57	1.46	1.35	1.23
12	2.14	2.20	2.25	2.28	2.31	2.32	2.32	2.30	2.27	2.23	2.18	2.11	2.03	1.95	1.85	1.74	1.62	1.50	1.36
13	2.16	2.22	2.27	2.31	2.34	2.35	2.34	2.33	2.30	2.26	2.20	2.14	2.06	1.97	1.87	1.76	1.64	1.52	1.38
14	2.03	2.09	2.14	2.17	2.19	2.20	2.20	2.18	2.15	2.11	2.06	2.00	1.92	1.84	1.74	1.64	1.53	1.41	1.28
15	1.77	1.81	1.85	1.87	1.89	1.89	1.88	1.87	1.84	1.80	1.75	1.70	1.63	1.56	1.47	1.38	1.29	1.18	1.08
16	1.38	1.41	1.43	1.44	1.45	1.45	1.44	1.42	1.39	1.36	1.32	1.27	1.22	1.16	1.09	1.02	.95	.87	.78
17	.90	.91	.92	.92	.92	.91	.90	.88	.86	.83	.80	.77	.73	.69	.64	.60	.55	.50	.44
18	.40	.39	.39	.39	.38	.37	.36	.35	.33	.32	.30	.28	.26	.24	.22	.21	.19	.17	.15
19	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

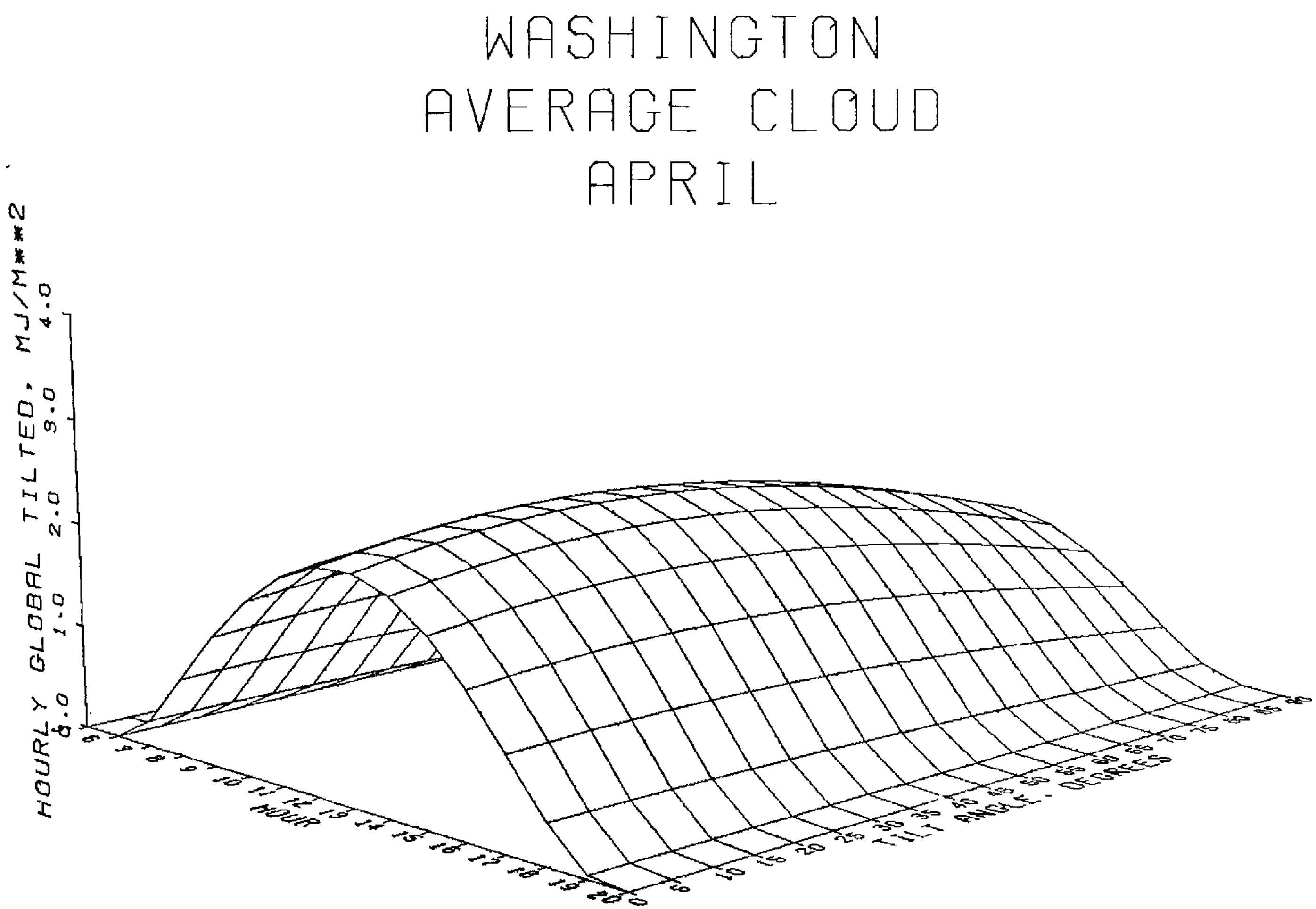

Figure 3.50. Washington Average Cloud April Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.51. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

JULY

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	.07	.06	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.03	.03	.03
	7	.51	.49	.47	.44	.41	.38	.34	.31	.28	.25	.23	.21	.19	.18	.18	.17	.17	.16	.16
	8	1.17	1.15	1.13	1.10	1.06	1.02	.97	.92	.87	.81	.74	.67	.60	.53	.46	.40	.35	.33	.32
	9	1.85	1.85	1.84	1.82	1.79	1.75	1.70	1.64	1.57	1.50	1.41	1.32	1.22	1.11	1.01	.89	.77	.66	.54
	10	2.45	2.47	2.48	2.47	2.45	2.42	2.37	2.31	2.23	2.14	2.04	1.93	1.81	1.68	1.54	1.40	1.24	1.09	.92
	11	2.90	2.94	2.97	2.97	2.96	2.93	2.89	2.83	2.75	2.65	2.54	2.42	2.28	2.13	1.97	1.80	1.62	1.43	1.24
HOUR	12	3.17	3.22	3.26	3.27	3.27	3.24	3.20	3.14	3.05	2.96	2.84	2.71	2.56	2.40	2.23	2.04	1.85	1.64	1.43
	13	3.23	3.28	3.32	3.33	3.33	3.31	3.26	3.20	3.12	3.02	2.90	2.77	2.62	2.46	2.28	2.09	1.90	1.69	1.47
	14	3.07	3.12	3.15	3.16	3.15	3.13	3.08	3.02	2.94	2.84	2.73	2.60	2.45	2.30	2.13	1.95	1.76	1.56	1.36
	15	2.71	2.74	2.76	2.76	2.75	2.71	2.67	2.60	2.53	2.43	2.33	2.21	2.08	1.94	1.79	1.63	1.46	1.28	1.10
	16	2.18	2.19	2.19	2.18	2.15	2.12	2.07	2.01	1.93	1.85	1.76	1.65	1.54	1.42	1.30	1.17	1.03	.89	.75
	17	1.53	1.53	1.51	1.48	1.45	1.41	1.36	1.30	1.24	1.17	1.09	1.01	.92	.83	.74	.64	.55	.46	.41
	18	.85	.83	.80	.77	.73	.69	.65	.61	.56	.51	.45	.40	.36	.32	.29	.27	.26	.25	.24
	19	.26	.24	.22	.20	.18	.16	.15	.13	.12	.11	.11	.11	.11	.10	.10	.10	.09	.09	.09
	20	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

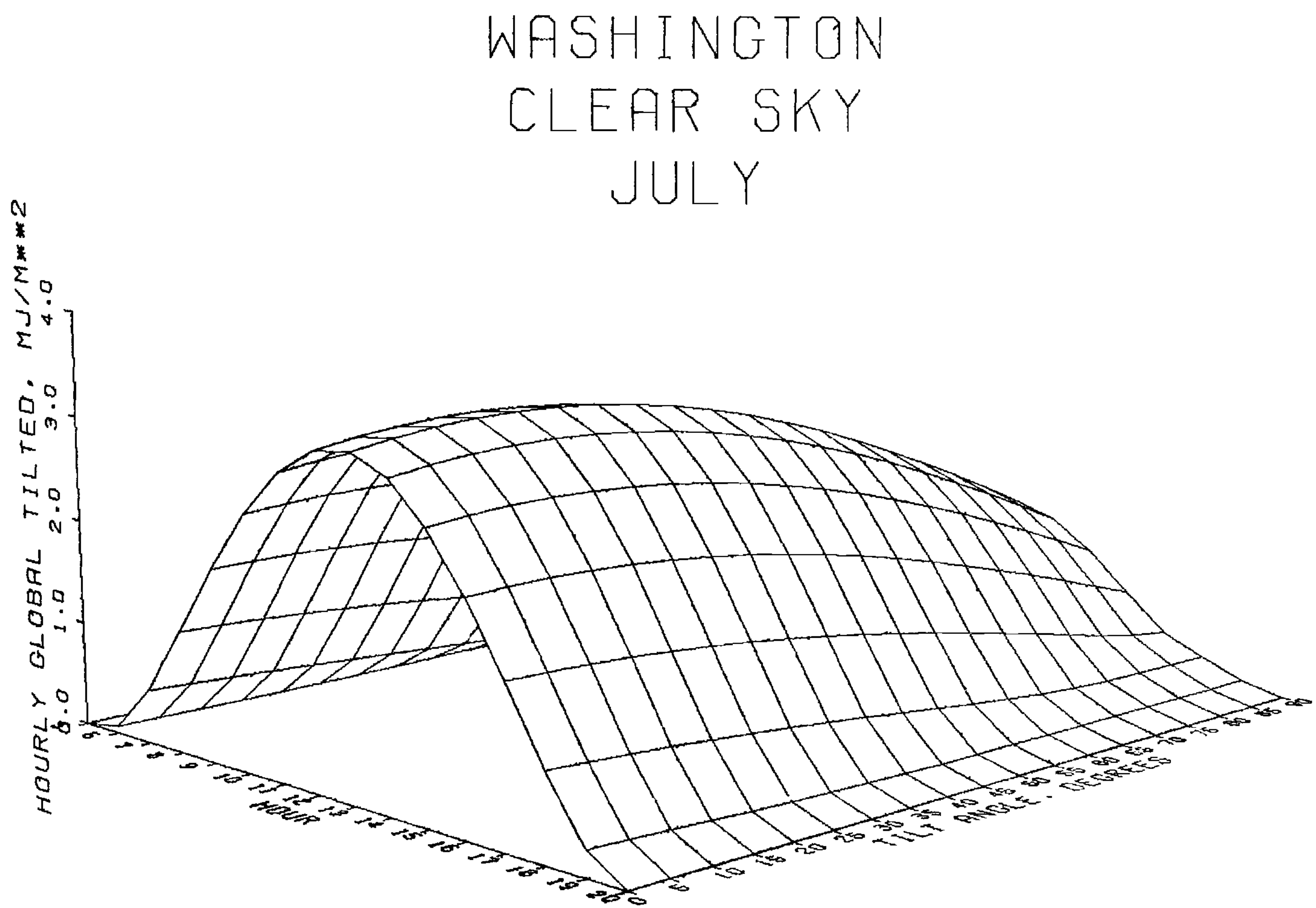

Figure 3.51. Washington Clear Sky July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.52. **WASHINGTON**

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

JULY

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	.06	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
	7	.40	.38	.37	.35	.33	.31	.29	.27	.25	.23	.22	.20	.19	.18	.18	.17	.16	.16	.15
	8	.87	.86	.85	.83	.81	.78	.75	.72	.68	.64	.60	.55	.51	.46	.41	.37	.34	.31	.30
	9	1.35	1.35	1.34	1.33	1.31	1.28	1.25	1.21	1.16	1.11	1.05	.99	.93	.86	.79	.71	.63	.56	.48
	10	1.76	1.77	1.77	1.77	1.75	1.73	1.69	1.65	1.60	1.54	1.48	1.40	1.32	1.24	1.14	1.05	.95	.85	.74
	11	2.07	2.09	2.10	2.10	2.09	2.07	2.04	1.99	1.94	1.88	1.80	1.72	1.63	1.53	1.43	1.31	1.20	1.08	.95
HOUR	12	2.25	2.28	2.30	2.30	2.29	2.27	2.24	2.20	2.14	2.07	2.00	1.91	1.81	1.71	1.59	1.47	1.35	1.21	1.08
	13	2.29	2.32	2.34	2.34	2.34	2.32	2.28	2.24	2.18	2.12	2.04	1.95	1.85	1.74	1.63	1.51	1.38	1.24	1.10
	14	2.18	2.21	2.22	2.23	2.22	2.20	2.16	2.12	2.07	2.00	1.92	1.84	1.74	1.64	1.53	1.41	1.29	1.16	1.03
	15	1.94	1.95	1.96	1.96	1.95	1.92	1.89	1.85	1.80	1.73	1.66	1.58	1.50	1.40	1.30	1.20	1.09	.98	.86
	16	1.58	1.58	1.58	1.57	1.55	1.53	1.49	1.45	1.40	1.35	1.29	1.22	1.14	1.06	.98	.90	.81	.71	.62
	17	1.13	1.12	1.11	1.10	1.07	1.05	1.01	.98	.93	.89	.84	.78	.73	.67	.61	.54	.48	.42	.38
	18	.64	.63	.61	.59	.57	.55	.52	.49	.46	.43	.39	.36	.33	.30	.28	.26	.25	.24	.23
	19	.20	.19	.18	.17	.16	.15	.14	.13	.12	.11	.11	.11	.10	.10	.10	.09	.09	.09	.08
	20	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

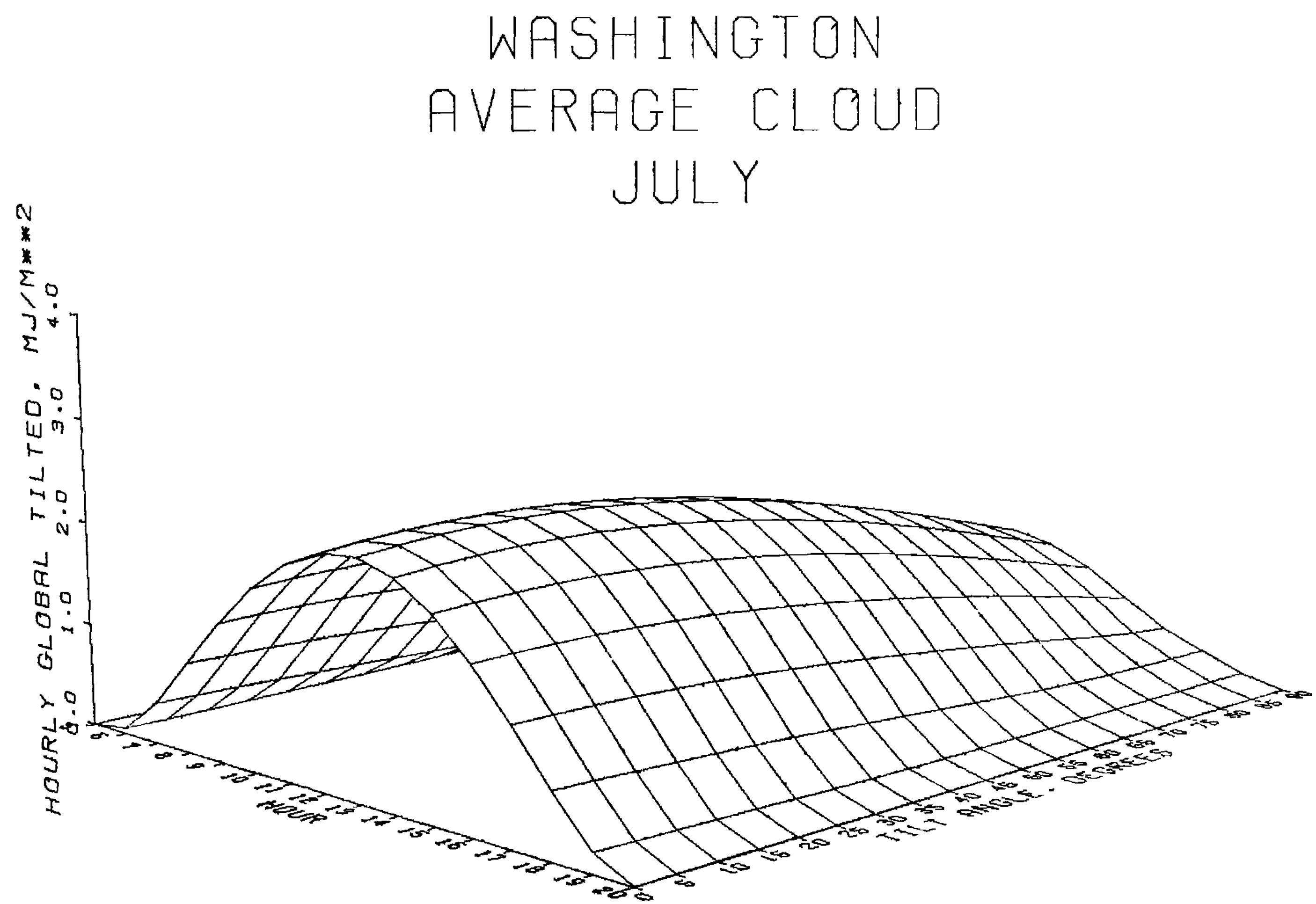

Figure 3.52. Washington Average Cloud July Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.53. **WASHINGTON**

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

CLEAR SKY

OCTOBER

	TILT ANGLE (DEGREES)																		
HOUR	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	.03	.04	.04	.05	.05	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
8	.45	.49	.53	.56	.59	.62	.65	.66	.68	.69	.70	.70	.70	.69	.68	.67	.65	.63	.60
9	1.09	1.17	1.25	1.33	1.39	1.44	1.49	1.52	1.55	1.57	1.58	1.57	1.56	1.54	1.50	1.46	1.41	1.35	1.28
10	1.67	1.79	1.90	2.01	2.10	2.17	2.23	2.28	2.32	2.34	2.34	2.33	2.30	2.26	2.21	2.14	2.05	1.96	1.85
11	2.08	2.24	2.37	2.50	2.60	2.69	2.77	2.82	2.86	2.88	2.88	2.87	2.83	2.77	2.70	2.61	2.51	2.39	2.25
12	2.29	2.46	2.61	2.74	2.86	2.96	3.04	3.10	3.13	3.15	3.15	3.13	3.09	3.03	2.95	2.85	2.73	2.60	2.45
13	2.27	2.44	2.59	2.72	2.83	2.93	3.01	3.07	3.11	3.13	3.13	3.11	3.07	3.01	2.93	2.83	2.71	2.58	2.43
14	2.03	2.17	2.31	2.43	2.53	2.62	2.70	2.75	2.79	2.81	2.81	2.79	2.76	2.70	2.64	2.55	2.45	2.33	2.20
15	1.53	1.70	1.80	1.90	1.99	2.06	2.12	2.17	2.20	2.22	2.22	2.21	2.19	2.15	2.10	2.03	1.96	1.87	1.77
16	.98	1.06	1.13	1.20	1.26	1.31	1.35	1.38	1.41	1.42	1.43	1.43	1.42	1.40	1.37	1.33	1.29	1.23	1.17
17	.35	.38	.41	.44	.47	.49	.51	.52	.54	.55	.55	.56	.55	.55	.54	.53	.52	.50	.48
18	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.03	.03	.03	.03	.03	.03	.02	.02
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

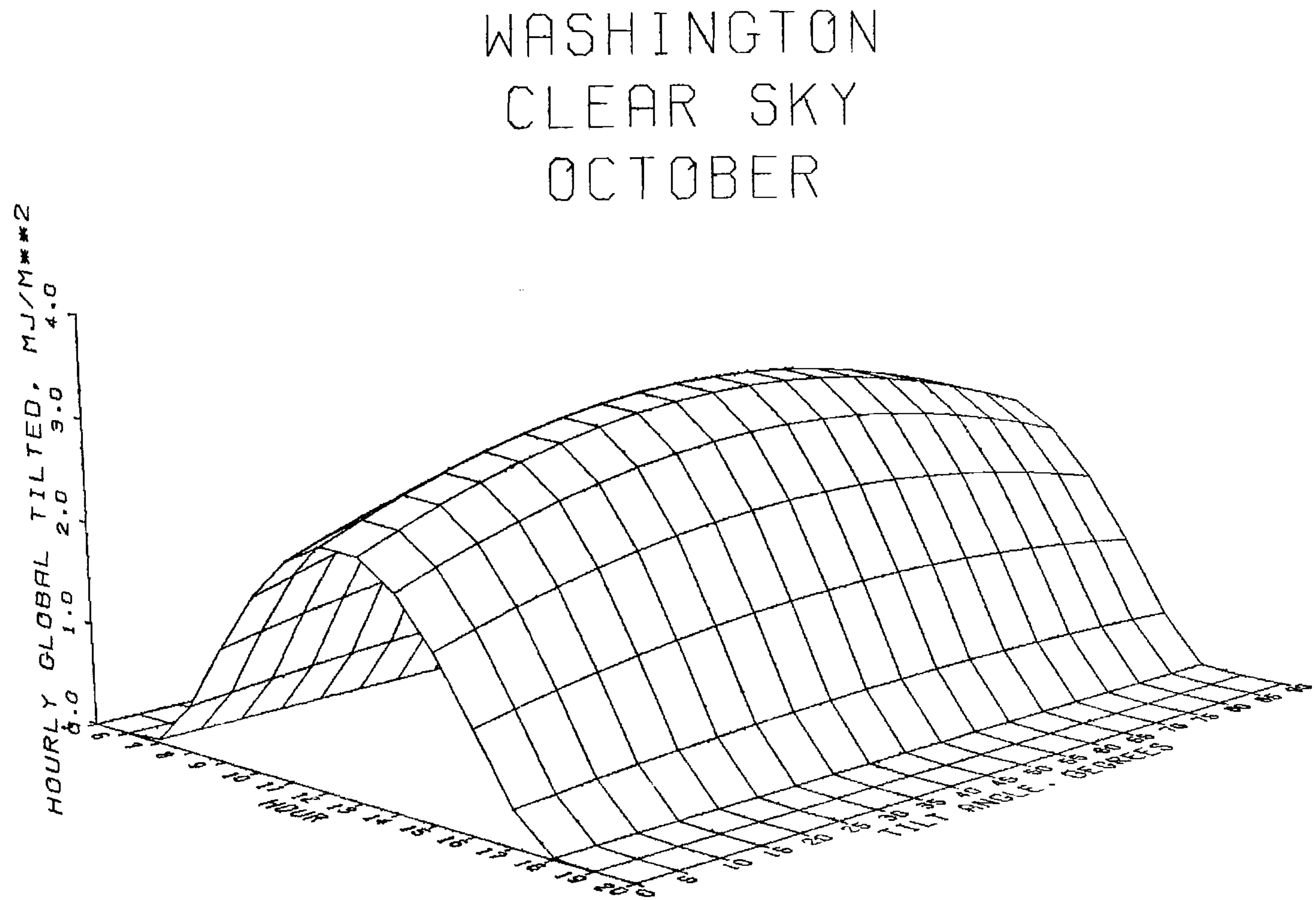

Figure 3.53. Washington Clear Sky October Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

Table 3.54. WASHINGTON

HOURLY GLOBAL TILTED RADIATION (MEGAJOULES/SQ.M.)

AVERAGE CLOUD

OCTOBER

TILT ANGLE (DEGREES)

		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	.03	.03	.03	.04	.04	.04	.04	.04	.04	.04	.04	.04	.05	.04	.04	.04	.04	.04	.04
	8	.36	.39	.41	.43	.45	.47	.48	.49	.50	.50	.51	.50	.50	.49	.49	.47	.46	.44	.42
	9	.84	.90	.94	.99	1.03	1.06	1.08	1.10	1.11	1.12	1.12	1.11	1.10	1.08	1.06	1.03	.99	.94	.90
	10	1.26	1.34	1.41	1.47	1.52	1.57	1.60	1.63	1.65	1.65	1.65	1.64	1.61	1.58	1.54	1.49	1.43	1.36	1.29
	11	1.56	1.66	1.74	1.82	1.88	1.93	1.97	2.00	2.02	2.03	2.02	2.00	1.97	1.93	1.88	1.81	1.74	1.65	1.56
HOUR	12	1.71	1.81	1.91	1.99	2.06	2.11	2.16	2.19	2.21	2.21	2.20	2.18	2.15	2.10	2.04	1.97	1.89	1.80	1.69
	13	1.70	1.80	1.89	1.97	2.04	2.10	2.14	2.17	2.19	2.20	2.19	2.17	2.13	2.09	2.03	1.96	1.87	1.78	1.68
	14	1.52	1.61	1.70	1.77	1.83	1.88	1.92	1.95	1.97	1.98	1.97	1.95	1.92	1.88	1.83	1.77	1.69	1.61	1.52
	15	1.20	1.27	1.34	1.40	1.45	1.49	1.52	1.55	1.56	1.57	1.57	1.56	1.53	1.50	1.47	1.42	1.36	1.30	1.23
	16	.76	.81	.86	.90	.93	.96	.98	1.00	1.01	1.02	1.02	1.02	1.00	.99	.96	.94	.90	.86	.82
	17	.29	.31	.32	.34	.35	.37	.38	.39	.39	.40	.40	.40	.40	.39	.39	.38	.37	.35	.34
	18	.01	.01	.01	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

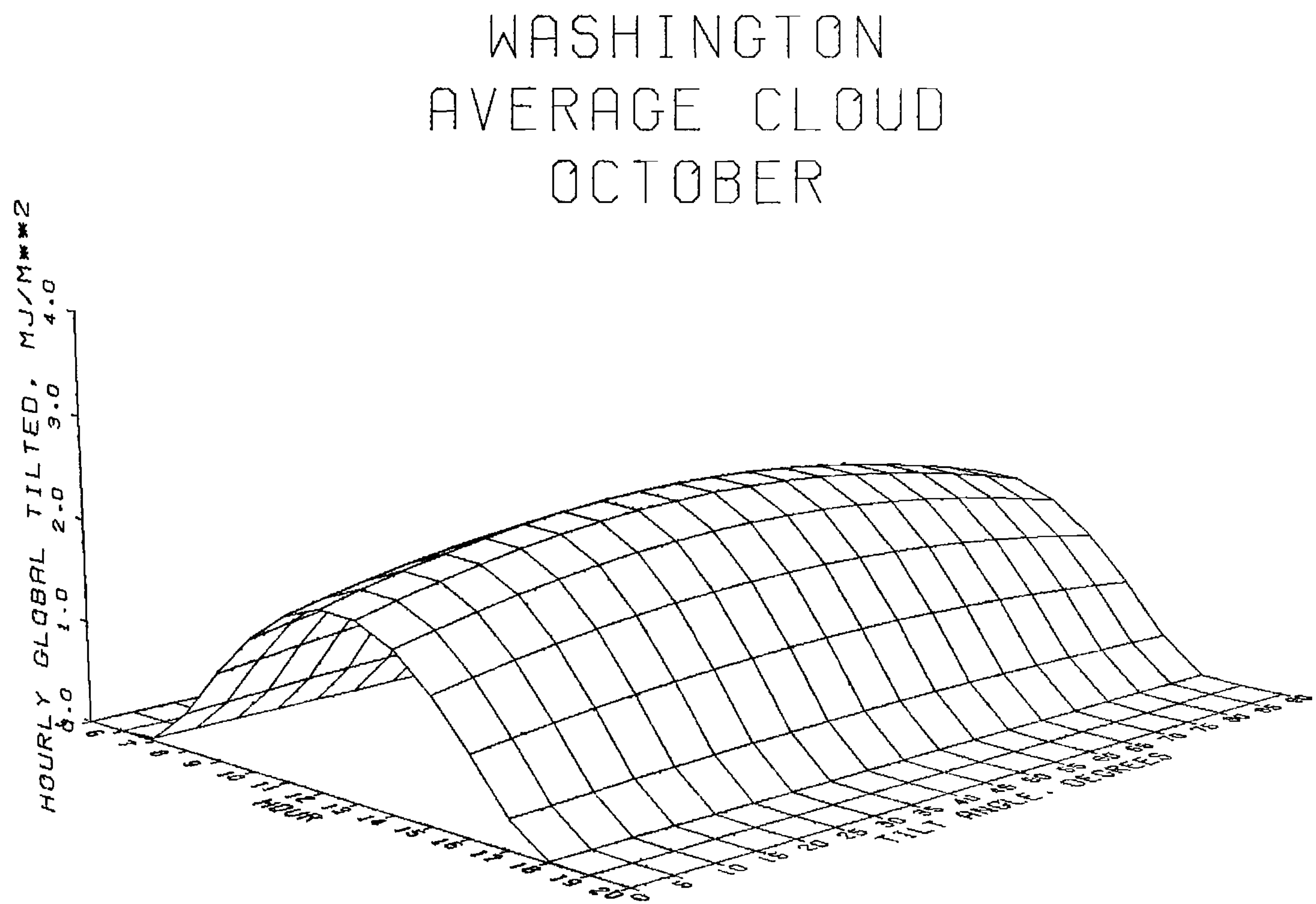

Figure 3.54. Washington Average Cloud October Hourly Global Tilted Radiation (Megajoules per Square Meter) versus Hour and Tilt Angle.

4. MODEL COMPARISONS

Figures 4.1-4.9 show graphically how monthly radiation values for global horizontal, global tilted, and direct insolation as calculated from the Watts (1978) report compared to observed values for Atlanta, Miami, and Washington, D.C. Again the "observed" values were not truly direct observations. The global horizontal values were taken from the Cinquemani (1978) report which interpolated mathematically, based on cloud cover and other meteorological factors, for neighboring stations from the rehabilitiated SOLMET data. These numbers then were used to generate the tilted values, by applying the Liu and Jordan (1960) method, and the direct radiation using our regression for monthly direct versus monthly global, as discussed in Section 2 and shown in Figure 2.0.

The calculated data were derived from the Watts report using the climatological values of percent sunshine, precipitable water, ozone, and albedo. The turbidity values used as input in some cases were modified from their given climatological values for as many as three or four of the twelve monthly values given, in order to bring the shape of the modeled seasonal variations into better agreement with the "observed" data. The adjusted turbidity values were within the range of original values for the surrounding months in all cases, however.

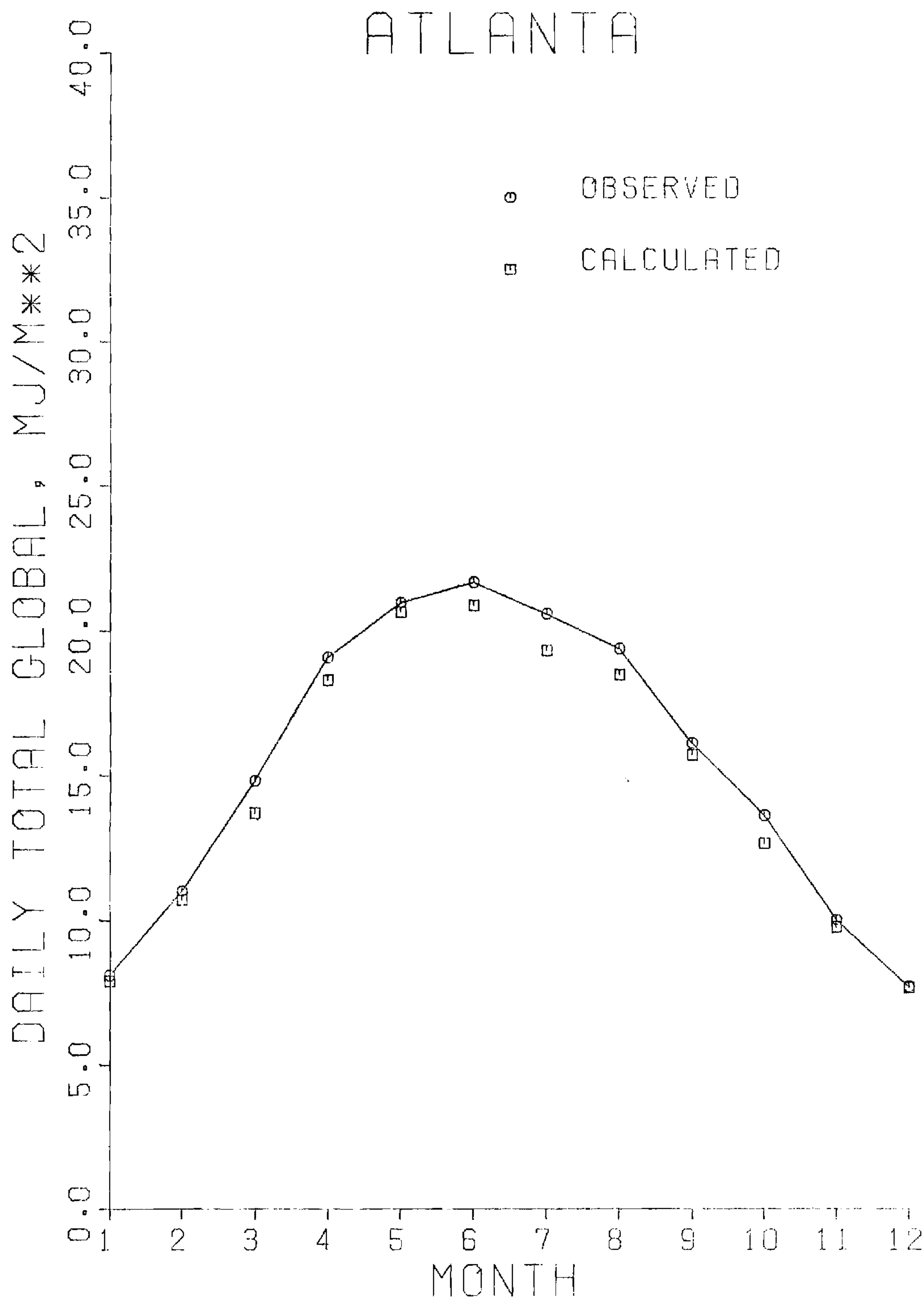

Figure 4.1. Atlanta Comparison Observed to Calculated Daily Total Global Radiation (Megajoules per Square Meter) versus Month.

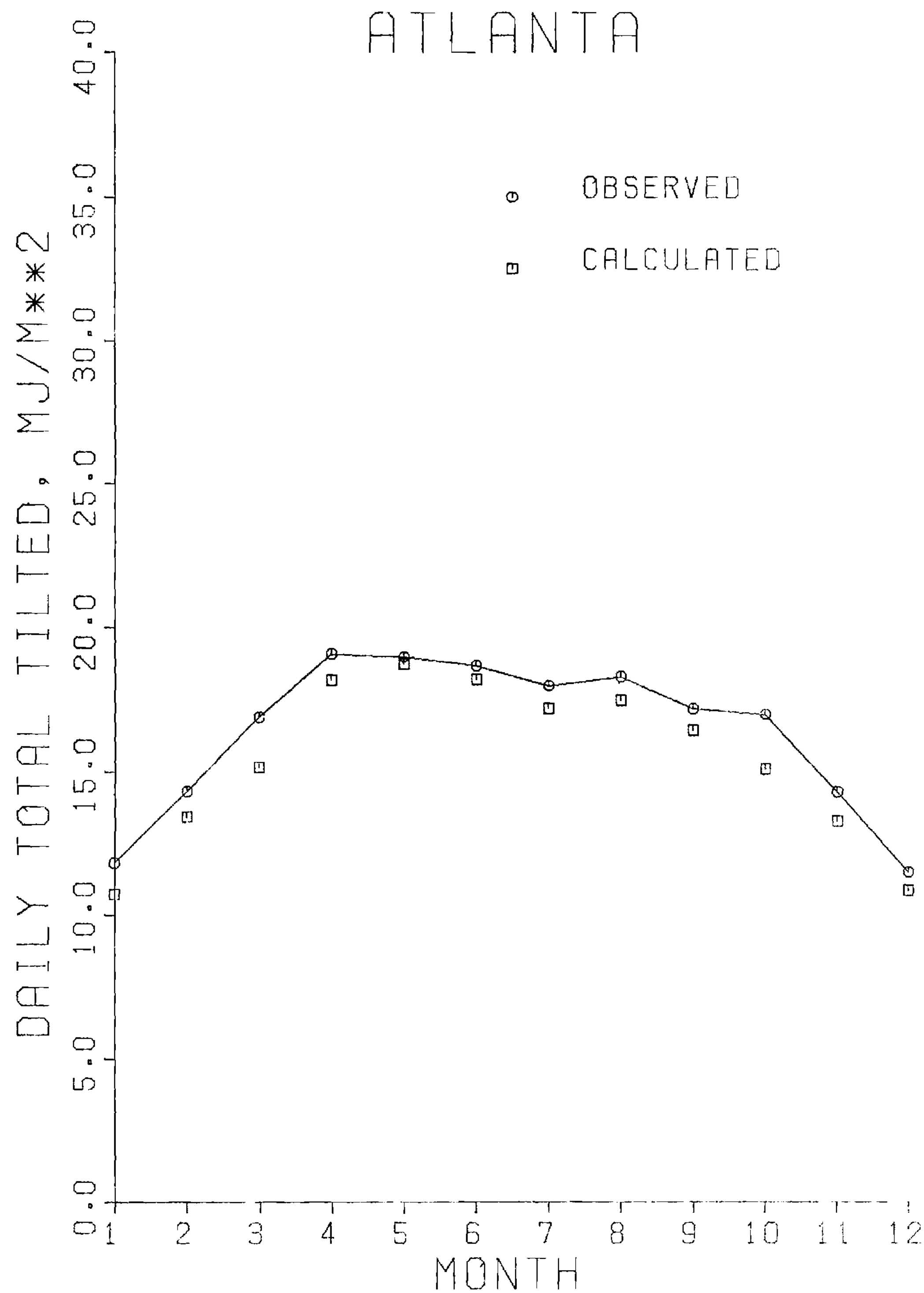

Figure 4.2. Atlanta Comparison Observed to Calculated Daily Total Tilted Radiation (Megajoules per Square Meter) versus Month.

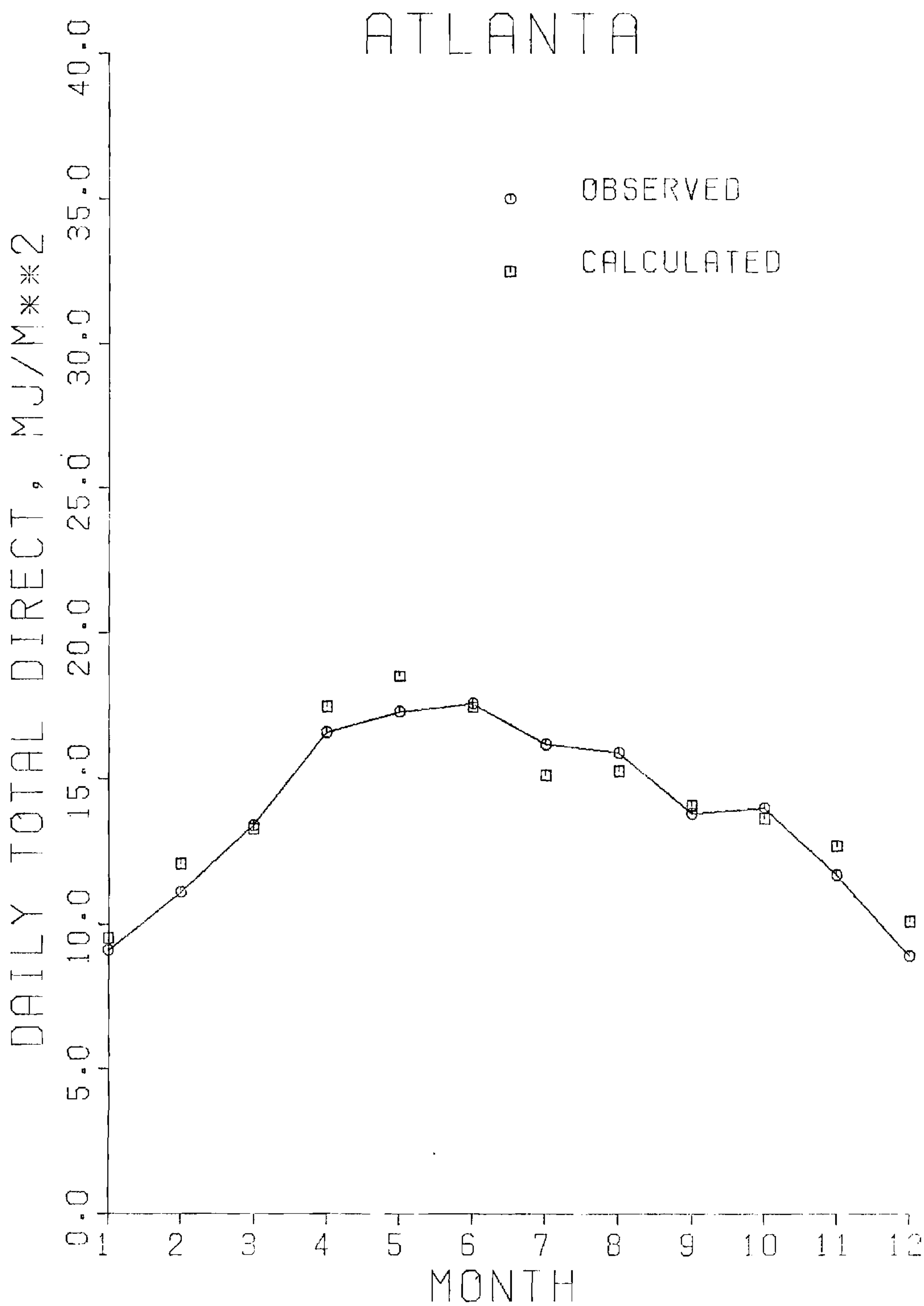

Figure 4.3. Atlanta Comparison Observed to Calculated Daily Total Direct Radiation (Megajoules per Square Meter) versus Month.

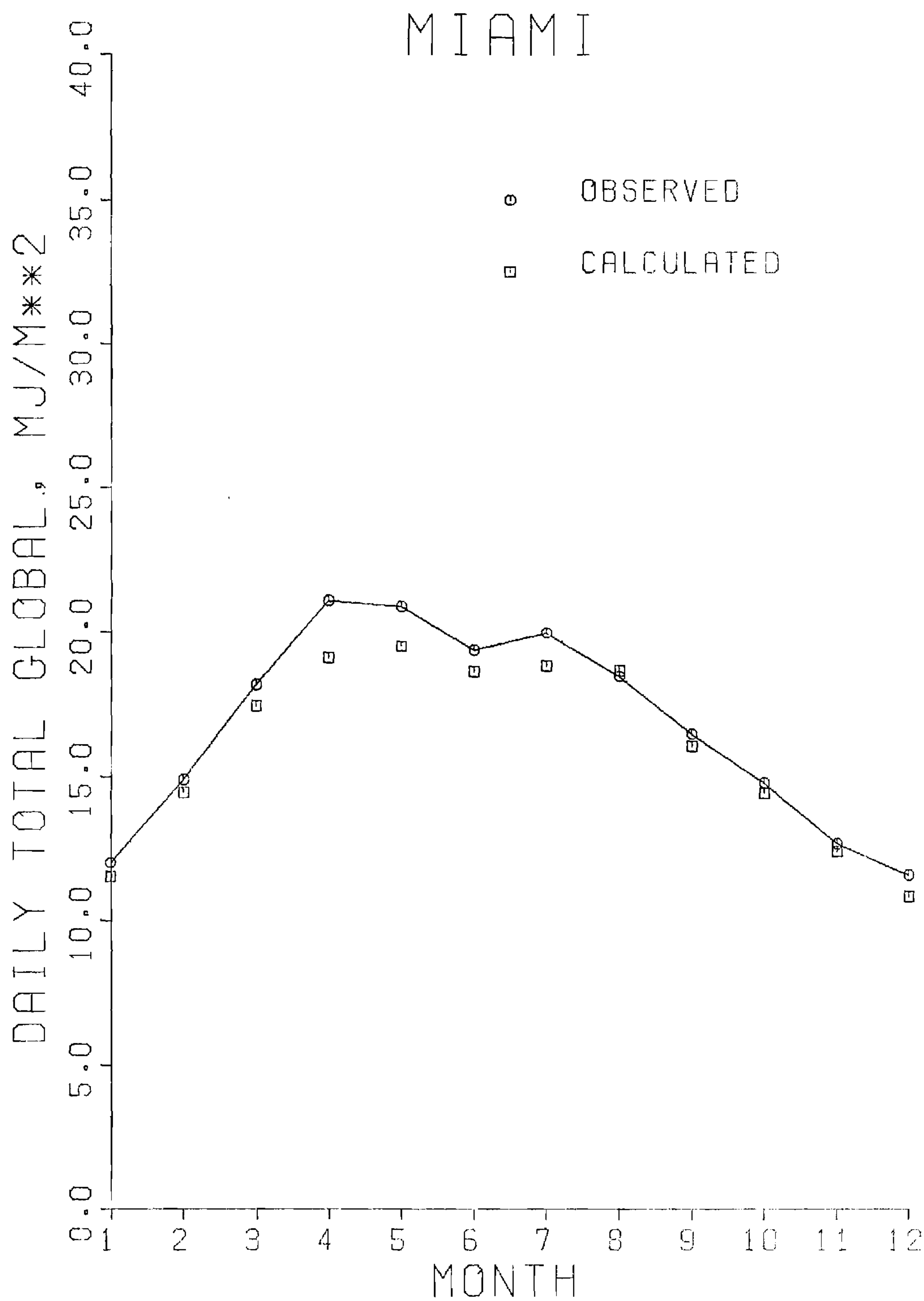

Figure 4.4. Miami Comparison Observed to Calculated Daily Total Global Radiation (Megajoules per Square Meter) versus Month.

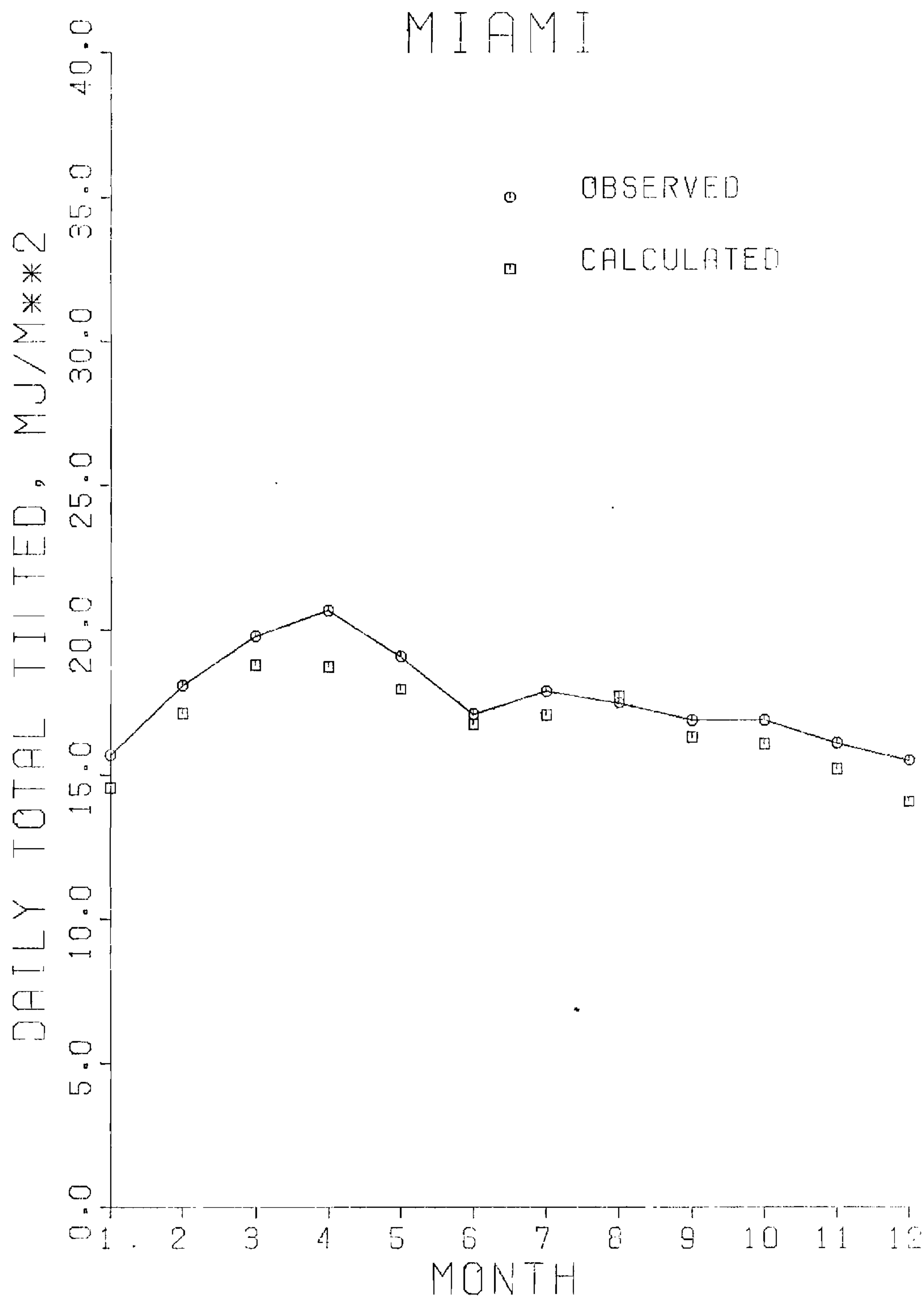

Figure 4.5. Miami Comparison Observed to Calculated Daily Total Tilted Radiation (Megajoules per Square Meter) versus Month.

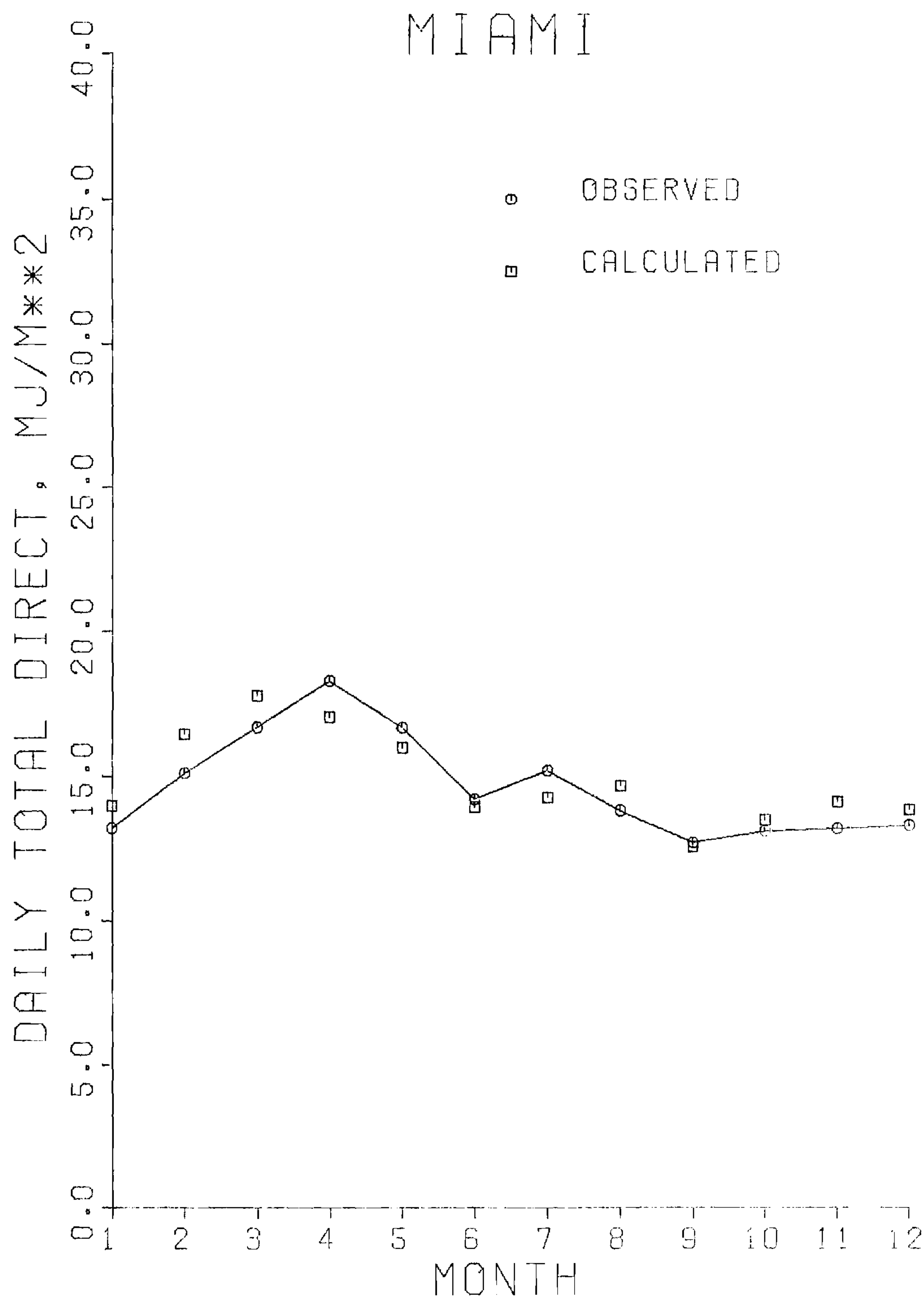

Figure 4.6. Miami Comparison Observed to Calculated Daily Total Direct Radiation (Megajoules per Square Meter) versus Month.

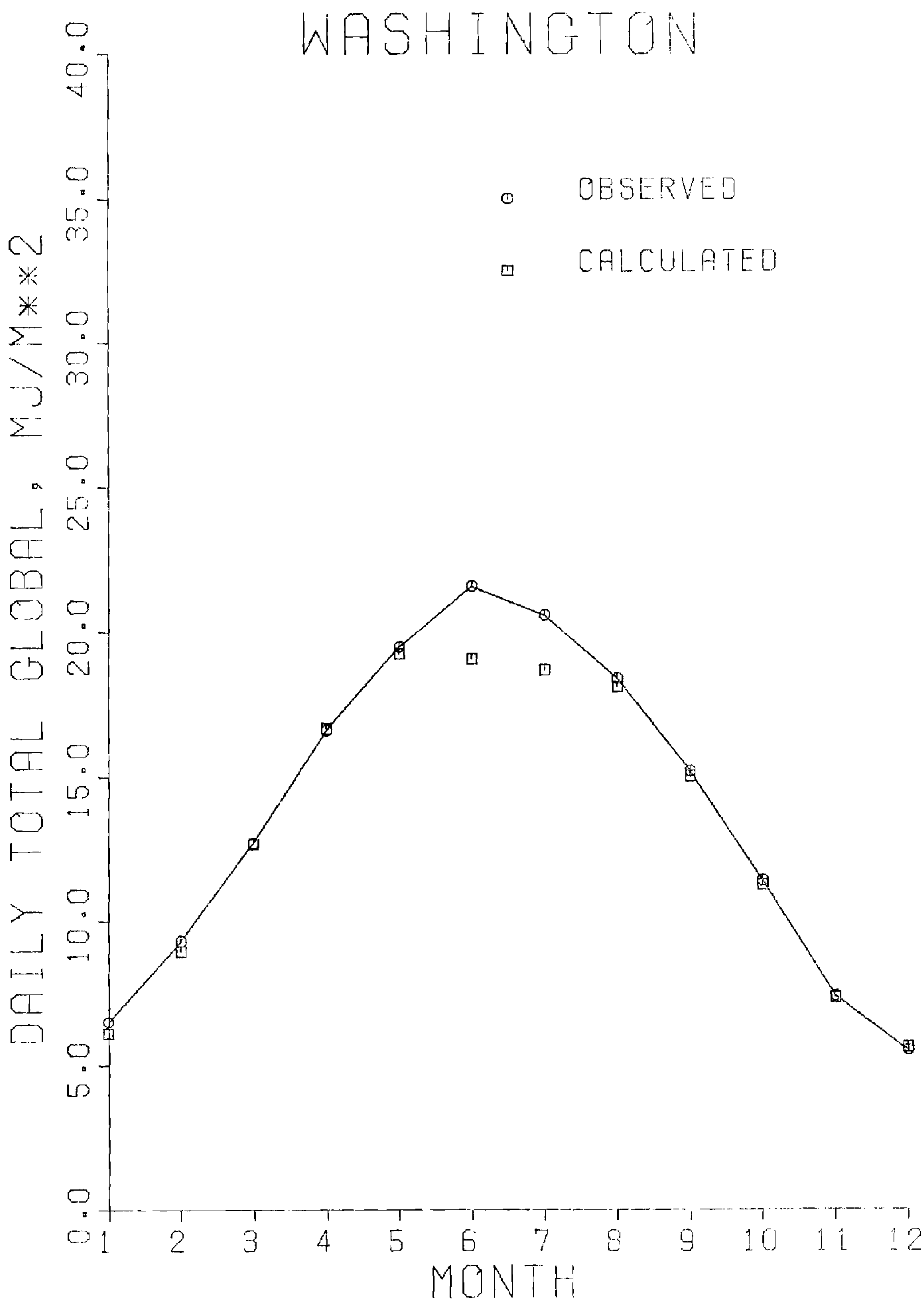

Figure 4.7. Washington Comparison Observed to Calculated Daily Total Global Radiation (Megajoules per Square Meter) versus Month.

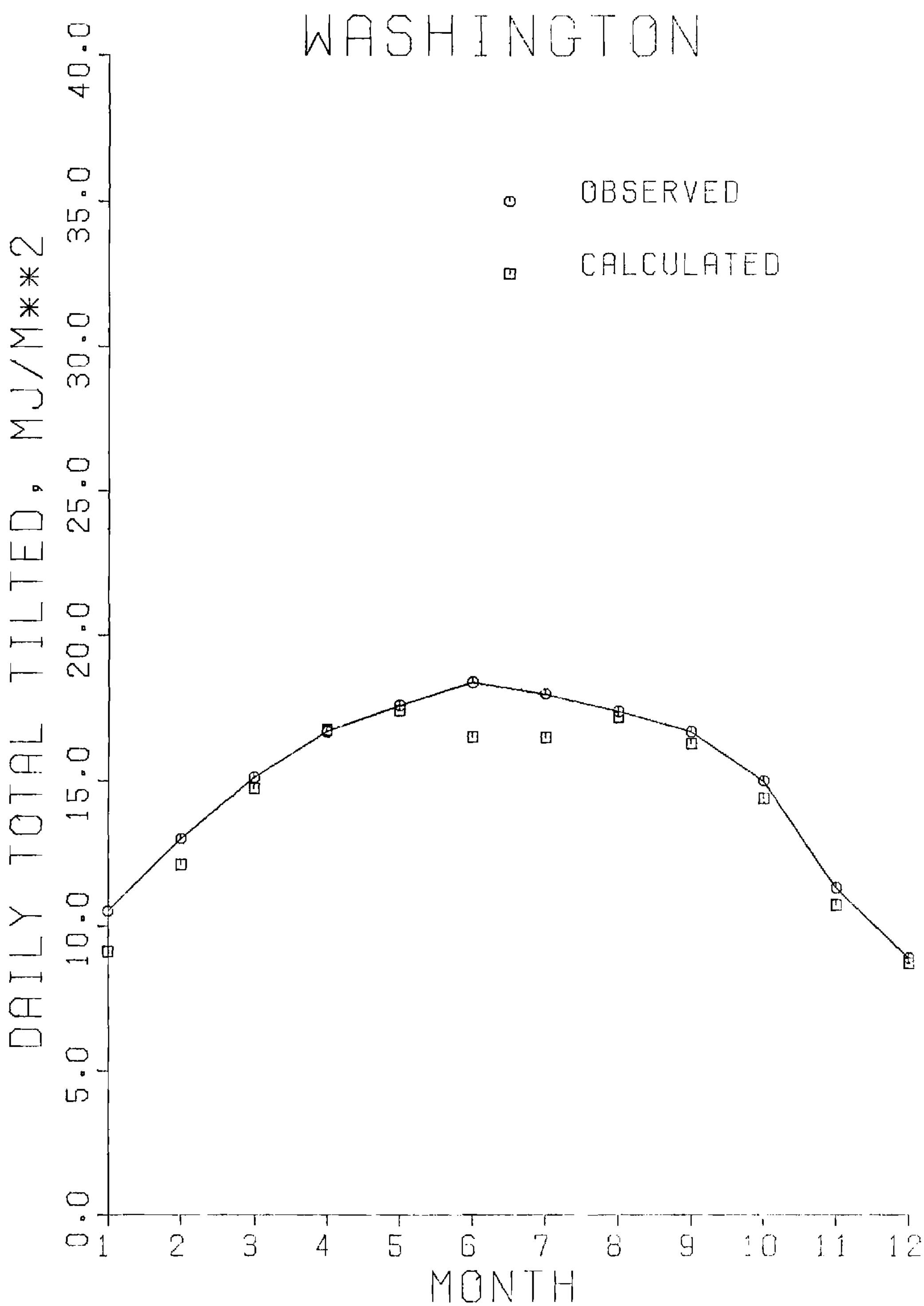

Figure 4.8. Washington Comparison Observed to Calculated Daily Total Radiation (Megajoules per Square Meter) versus Month.

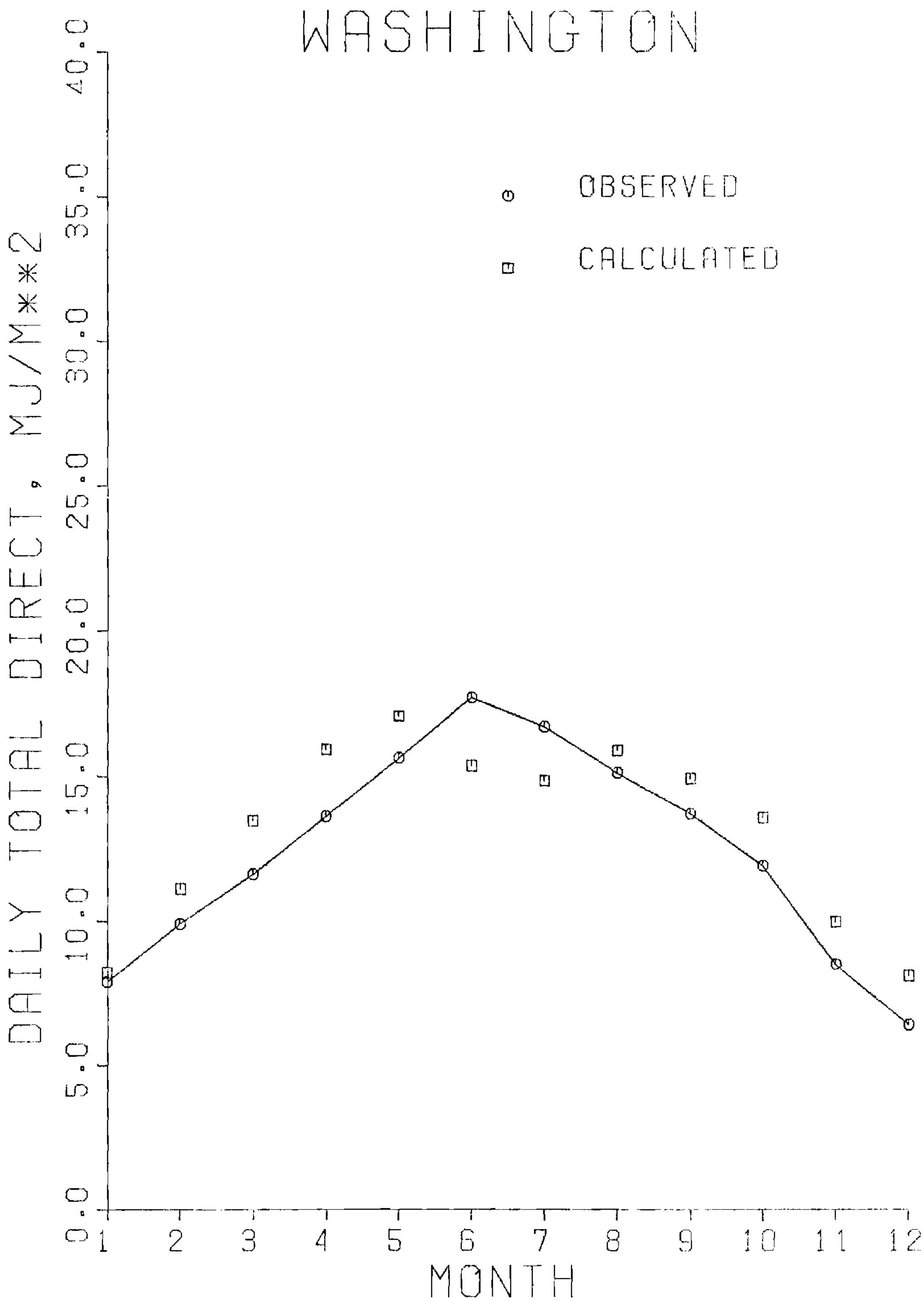

Figure 4.9. Washington Comparison Observed to Calculated Daily Total Direct Radiation (Megajoules per Square Meter) versus Month.

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Appendix A. Energy Conversions.

1 Btu = 1.06 kJ

1 cal = 4.186 J

1 langley = 1 cal/cm^2 = 41.86 kJ/m^2

1 Btu/ft^2 hr = 3.153 W/m^2

1 MJ/m^2 hr = 88.1 Btu/ft^2 hr